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V/STOL TILT ROTOR AIRCRAFT STUDY

VOLUME V

DEFINITION OF STOWED ROTOR RESEARCH AIRCRAFT

MARCH 1973

(NASA-CR-114598) V/STOL TILT ROTOR AIRCRAFT STUDY. VOLUME 5: DEFINITION OF STOWED ROTOR RESEARCH AIRCRAFT (Boeing Vertol Co., Philadelphia, Pa.) 130 p HC $8.75 CSCL 01C G3/02

N73-30009

Unclas 11263

Prepared Under Contract No. NAS2-6598 by
BOEING VERTOL COMPANY
BOEING CENTER
P. O. Box 16858
Philadelphia, Pennsylvania 19142

for

Ames Research Center
National Aeronautics and Space Administration
and
United States Army Air Mobility Research and Development Laboratory
Ames Directorate

BOEING D222-10060-1

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THE BOEING COMPANY

VERTOL DIVISION · PHILADELPHIA, PENNSYLVANIA

CODE IDENT. NO. 77272

NUMBER D222-10060-1

TITLE V/STOL TILT ROTOR AIRCRAFT STUDY - DEFINITION OF STOWED ROTOR RESEARCH AIRCRAFT

ORIGINAL RELEASE DATE [illegible]. FOR THE RELEASE DATE OF SUBSEQUENT REVISIONS, SEE THE REVISION SHEET. FOR LIMITATIONS IMPOSED ON THE DISTRIBUTION AND USE OF INFORMATION CONTAINED IN THIS DOCUMENT, SEE THE LIMITATIONS SHEET.

MODEL 222 CONTRACT NAS2-6598

ISSUE NO. ______ ISSUED TO: ______

PREPARED BY	V. Soule Virgil H. Soule	DATE	3/1/73
APPROVED BY	A. Schoen	DATE	
APPROVED BY	K. Gillmore	DATE	[illegible]
APPROVED BY	D. Richardson	DATE	4/5/73
APPROVED BY	W. Peck	DATE	4/5/73

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REVISIONS

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A	NASA comments incorporated	7-12-73	S

FOREWORD

This report is one of a series prepared by The Boeing Vertol Company, Philadelphia, Pennsylvania for the National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California under contract NAS2-6598. The studies reported under Volumes I through IV and VIII through X were jointly funded by NASA and the U.S. Army Air Mobility Research and Development Laboratory, Ames Directorate. Volumes V through VII were funded by the U.S. Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio.

This contract was administered by the National Aeronautics and Space Administration. Mr. Richard J. Abbott was the Contract Administrator, Mr. Gary B. Churchill, Tilt Rotor Research Aircraft Project Office, was the Technical Monitor, and coordination and liaison with the U.S. Air Force Flight Dynamics Laboratory was through Mr. D. Fraga.

The complete list of reports published under this contract is as follows:

Volume I -- Conceptual Design of Useful Military and/or Commercial Aircraft, NASA CR-114437

Volume II -- Preliminary Design of Research Aircraft, NASA CR-114438

Volume III -- Overall Research Aircraft Project Plan, Schedules, and Estimated Cost, NASA CR-114439

Volume IV -- Wind Tunnel Investigation Plan for a Full Scale Tilt Rotor Research Aircraft, CR-114440

Volume V -- Definition of Stowed Rotor Research Aircraft, NASA CR-114598

Volume VI -- Preliminary Design of a Composite Wing for Tilt Rotor Aircraft, NASA CR-114599

Volume VII -- Tilt Rotor Flight Control Program Feedback Studies, NASA CR-114600

Volume VIII -- Mathematical Model for a Real Time Simulation of a Tilt Rotor Aircraft (Boeing Vertol Model 222), NASA CR-114601

Volume IX -- Piloted Simulator Evaluation of the Boeing Vertol Model 222 Tilt Rotor Aircraft, NASA CR-114602

Volume X -- Performance and Stability Test of a 1/4.622 Froude Scaled Boeing Vertol Model 222 Tilt Rotor Aircraft (Phase 1), NASA CR-114603

ABSTRACT

This report presents the results of a study of folding tilt rotor (stowed rotor) aircraft. The effects of design cruise speed on the gross weight of a conceptual design USAF Search and Rescue stowed rotor aircraft are shown and a comparison is made with a conventional (non-folding) tilt rotor aircraft. A flight research stowed rotor design is presented, based on modifications to the NASA/Army tilt rotor demonstrator aircraft (Boeing Model 222). The program plans, including costs and schedules, are shown for the research aircraft development and a wind tunnel plan is presented for a full scale test of the aircraft.

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1.0 SUMMARY

This report presents the results of a study of folding tilt rotor (stowed rotor) aircraft. The stowed rotor is a variation of the basic tilt rotor design and has rotors which can be stopped (feathered) and folded in flight into smoothly faired wing tip nacelles while propulsion is provided by cruise fans. The advantage of this concept over the basic tilt rotor is that it is capable of higher cruise speeds while retaining the low speed rotor-borne agility and hover capability of the tilt rotor. This study is a follow-on counterpart to a study performed in 1971-72 on tilt rotor aircraft and includes identical considerations:

a. Conceptual design of useful aircraft for the 1975-80 time period

b. Preliminary design of a research aircraft for proof-of-concept demonstration

c. Program plans, cost, and schedules for a research aircraft program

d. Test plan for a full scale wind tunnel test of the research aircraft to be conducted prior to the flight test program

The conceptual design study (part a) includes a direct comparison of tilt rotor and stowed rotor aircraft for a range of design cruise speeds from 300 knots to 450 knots for a USAF Search and Rescue (SAR) mission. A gross weight cross-over point is shown to exist at about 360 knots design speed. For required cruise speeds in excess of that cross-over point, the

stowed rotor is lighter than the tilt rotor while the tilt rotor is lighter at the lower speeds. The design gross weight is shown to increase rapidly with cruise speed above the speed at which cruise and hover requirements for installed power exactly match. Based on that consideration, design point aircraft were selected for both tilt rotor and stowed rotor concepts, each with closely matched cruise and hover requirements. The stowed rotor, designed for 400 knots cruise speed, weighs 19070 pounds and uses 30.3 foot diameter rotors. The tilt rotor, designed for a 300 knot cruise capability, weighs 15,631 pounds and has 27 foot rotors.

The preliminary design study (part b) discusses the modifications required to the Boeing Model 222 tilt rotor research aircraft in order to demonstrate stowed rotor capabilities. The aircraft uses the 26 foot diameter rotors designed for the Model 222, one of which has been built and successfully tested in the NASA Ames 40 ft x 80 ft wind tunnel. The rotor hubs were modified to permit folding of the blades. The Lycoming T53-L-13B (modified) engines of the Model 222 are retained for rotor drive, although they are moved inboard to approximately 80% span to facilitate folding of the blades. For cruise flight, Garrett Airesearch TFE-731-2 turbofans are mounted on the wing further inboard (approximately 55% span). Design gross weight for the aircraft is 15,750 pounds compared to the 12,000 pounds of the March 1972 tilt rotor demonstrator aircraft.

2.0 INTRODUCTION

In March 1972, the Boeing Company completed a study of tilt rotor aircraft (References 1 through 4) under the joint sponsorship of NASA and the U.S. Army. That study covered the conceptual design of useful military and civil tilt rotor aircraft for the 1975-1980 time period, the preliminary design of a flight research aircraft, program costs and schedules, and the development of a wind tunnel test plan for a full scale tilt rotor test. It was shown that the existing technology base is sufficient to start building a technology demonstrator aircraft now, leading to useful tilt-rotor aircraft for military and/or civil applications in the 1975-1980 time period. That study was part of a current NASA/Army-sponsored program to design and develop two flight research tilt rotor aircraft, providing final verification of the status of technology and demonstrating the operational potential of the tilt rotor concept.

Concurrently with the development of tilt rotor technology, supported primarily by NASA, the U.S. Army, and the aircraft industry, studies have been conducted under U.S. Air Force sponsorship of the folding-tilt-rotor aircraft. This concept, a variation of the basic tilt rotor, is designed with rotors which can be stopped in flight so that the blades can be folded into wing-tip-mounted nacelles. Propulsion is provided by convertible engines which are capable of supplying shaft power for the rotor-drive or fan power for cruise flight.

Boeing studies conducted in 1971 for the U.S. Air Force Flight Dynamics Laboratory (Reference 5) were centered on stowed rotor aircraft for three different missions - rescue, capsule recovery, and transport. These aircraft weighed between 67,000 and 35,000 pounds, based on the requirement to meet very stringent mission criteria. For example, the search and rescue aircraft at 67,000 pounds carried a crew of five, picked up 1200 pounds of rescuees (6 men) at the mid point of a 500 n.m. radius hi-lo-lo-hi mission and was required to hover at mid point with one engine inoperative. By comparison, the search and rescue tilt rotor aircraft of the recent NASA/Army study, with carefully selected reductions in mission requirements, weighed 16,970 pounds. This aircraft flew a 500 n.m. hi-hi mission with a crew of four, picked up 3 rescuees at mid point and did not have an engine-out requirement.

In addition to the conceptual design studies of the stowed tilt rotor aircraft, analytic development and wind tunnel tests (References 6 through 12) demonstrated that the additional technology was available to bridge the gap between the tilt rotor and stowed-tilt-rotor aircraft. Development of a flight research aircraft is the next logical step.

In 1972, with the growing interest in the tilt rotor concept and with the development of a strong NASA/Army program to build and flight-test two tilt rotor research aircraft, the U.S. Air Force Flight Dynamics Laboratory asked Boeing,

through an add-on to the NASA contract, to re-examine the stowed rotor aircraft program with the following objectives:

1. Compare the potential operational capabilities of the stowed rotor aircraft with those of one or more of the conceptual design tilt rotor configurations from the NASA/Army study using common design ground rules.

2. Do a preliminary design of a stowed rotor research aircraft, based on either modifying the tilt rotor flight demonstrator or on a new research aircraft development.

3. Define the program costs and schedules to develop the recommended research aircraft.

4. Establish a plan for the wind tunnel test of the full scale stowed rotor research aircraft.

This report presents the results of that study. Section 3 describes the conceptual design of useful aircraft for the 1975-80 time period. Section 4 discusses the preliminary design of a stowed rotor research aircraft. Sections 5 and 6 present plans for the research aircraft development and wind tunnel test respectively.

3.0 CONCEPTUAL DESIGN OF STOWED ROTOR AIRCRAFT

3.1 INTRODUCTION

The conceptual design study of useful tilt rotor aircraft conducted by Boeing in 1971-72 (Reference 1) resulted in showing that the U.S. Air Force SAR (Search and Rescue) mission effectiveness can be significantly improved by application of the tilt rotor which combines the capabilities of the helicopters and fixed wing aircraft which are currently used as a coordinated rescue team.

Three other missions were identified in Reference 1 study as being desirable for the tilt rotor but were not studied for stowed rotor application because improved speed was of less importance. The other missions are a U.S. Army MAVS, U.S. Navy Sea Control aircraft, and Civil offshore oil rig support aircraft. Of the four missions, only the USAF SAR would obtain sufficient additional benefit from the increased speed capability of the stowed rotor concept to offset its additional design and manufacturing complexity and its increased size and cost.

For the SAR mission, the key factor is the reaction time of the rescue system relative to that of the hostile force in the vicinity of the rescue site. Improved responsiveness is clearly the element of greatest importance for a successful rescue. Consequently, of the four missions identified

for the tilt rotor in the 1975-80 time period, only the SAR mission was re-examined for the stowed rotor concept.

Early in the study the effort was broadened, at government request, to compare the effects of design cruise speed on the gross weight of the stowed rotor and the tilt rotor. Both stowed rotor and tilt rotor aircraft were studied over the range of design speeds from 300 knots to 450 knots.

3.2 TRADEOFF STUDIES

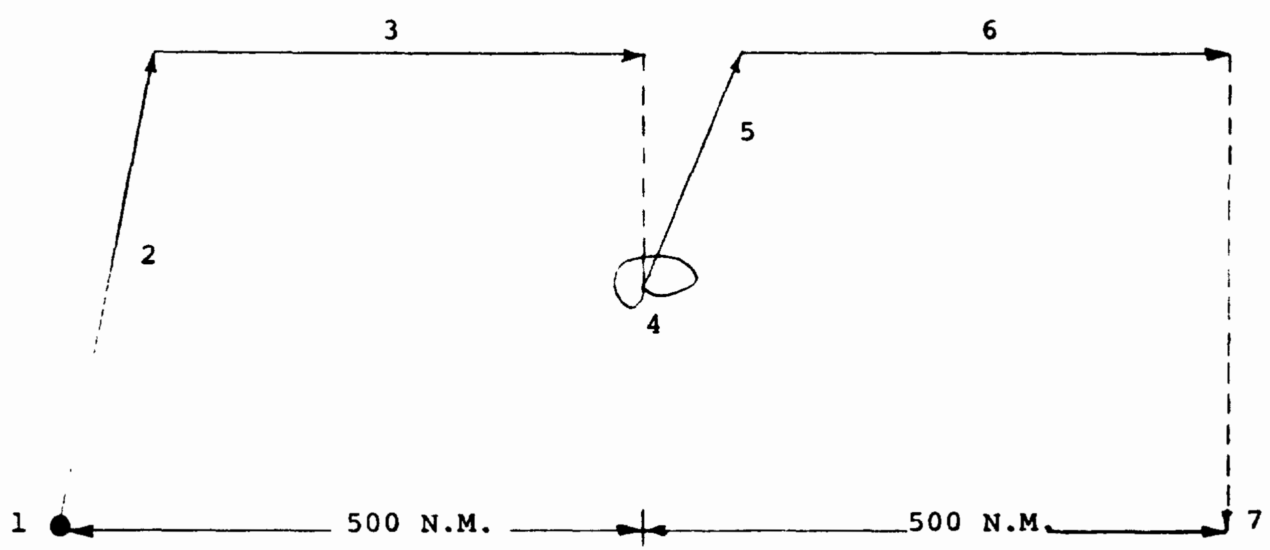
3.2.1 DESIGN CONSIDERATIONS

3.2.1.1 Mission Profile

The aircraft defined in the study were sized to perform a 500 NM Search and Rescue (SAR) mission (Figure 3-1). This is a "HI-HI" mission consisting of a takeoff at SL/95°F, climb to optimum altitude, cruise out at NRP to the 500 NM radius, hover for 1/2 hour at 5000 ft/95°F and recover three (3) rescuees, and return without inflight refueling. The optimum cruise altitude (based on minimum fuel) was found to be 20,000 ft.

The aircraft were assumed to carry a four-man crew consisting of two pilots, a crew chief, and a paramedic. The mission load was specified as 150 lb of rescue equipment (litters, forest penetrator, rescue sling, etc.), airborne electronics and equipment required to locate the rescuee, and a 5.56 mm machine gun and ammunition.

The engines, rotors, and drive system were sized by an alternate mission requirement. This was that the aircraft be capable of hovering at the mission midpoint at T/W=1.1 with a total of seven rescuees - the additional four rescuees being the crew of a downed sister ship. It was assumed that inflight refueling would be allowed under these conditions so that the mission fuel requirement is determined by the basic mission shown in Figure 3-1.



1. WARM UP, TAXI AND TAKEOFF: 3 MIN. @ NORMAL RATED POWER, SEA LEVEL,95°F
2. CLIMB TO OPTIMUM ALTITUDE @ MILITARY POWER AND SPEED FOR MAXIMUM RATE OF CLIMB
3. CRUISE OUTBOUND @ NORMAL RATED POWER SPEED
4. HOVER 1/2 HR., EFFECT RESCUE OF 3 PEOPLE (600 LBS) @ 5000'/95°F, MILITARY POWER
5. CLIMB TO OPTIMUM ALTITUDE @ MILITARY POWER AND SPEED FOR MAXIMUM RATE OF CLIMB
6. CRUISE INBOUND @ NORMAL RATED POWER SPEED
7. LAND WITH 10% (INITIAL) FUEL RESERVE

NOTES:

1. MISSION FLOWN @ STANDARD ATMOSPHERE CONDITIONS UNLESS OTHERWISE NOTED.
2. SFC INCREASED 5% PER MIL-C-5011A

FIGURE 3-1. DESIGN MISSION PROFILE - SAR HI-HI MISSION

3.2.1.2 Wing Design

3.2.1.2.1 Wing Planform

It is desirable, for a number of reasons, to use an unswept wing on the stowed rotor aircraft. The reasons are:

1) The importance of placing the longitudinal position of the nacelle hinge in reasonable proximity to the aircraft center of gravity and the wing aerodynamic center, to reduce pitch control requirements in hover.

2) The geometric complications related to wing-to-rotor clearance and nacelle overhang which are introduced with the use of an aft swept wing.

3) Minimization of tooling and materials complexity and overall reduction in manufacturing cost inherent to the straight, untapered wing design.

4) The elimination of either a bevel box or a universal coupling for the interconnecting cross shaft at the center of the fuselage which would be required with a swept wing.

For these reasons, a straight, untapered wing was selected for the aircraft in this study.

3.2.1.2.2 Airfoil Section and Thickness

The selection of a straight, untapered wing immediately led to a study of wing thickness and its relationship to drag divergence Mach number. Thick wings are desirable both from a weight-for-strength consideration and to provide adequate stiffness to eliminate potential dynamic problems with air resonance or whirl flutter (although this latter mode is not a consideration for the stowed rotor since its high speed flight is with rotors folded, it is a potential problem for the tilt rotor). Wing strength is a particularly important consideration for these configurations, since they are literally picked-up by the wing tips in hover flight. Although thick wings provide the needed strength and stiffness at minimum weight, they also reduce the drag divergence Mach number. The stowed rotor aircraft considered in this study have flight Mach numbers up to 0.732 (450 knots at 20,000 foot altitude). Use of conventional NACA airfoil sections would require wing thickness no greater than 13% to avoid drag divergence at those flight speeds. This would result in a significant weight penalty relative to the tilt rotor aircraft of Reference 1 which used airfoils of 21% thickness.

Fortunately, recent research has led to the development of the supercritical airfoil and has dramatically increased the drag divergence Mach number for thick airfoils. Figure 3-2 compares the capabilities of the conventional NACA 63 series airfoil

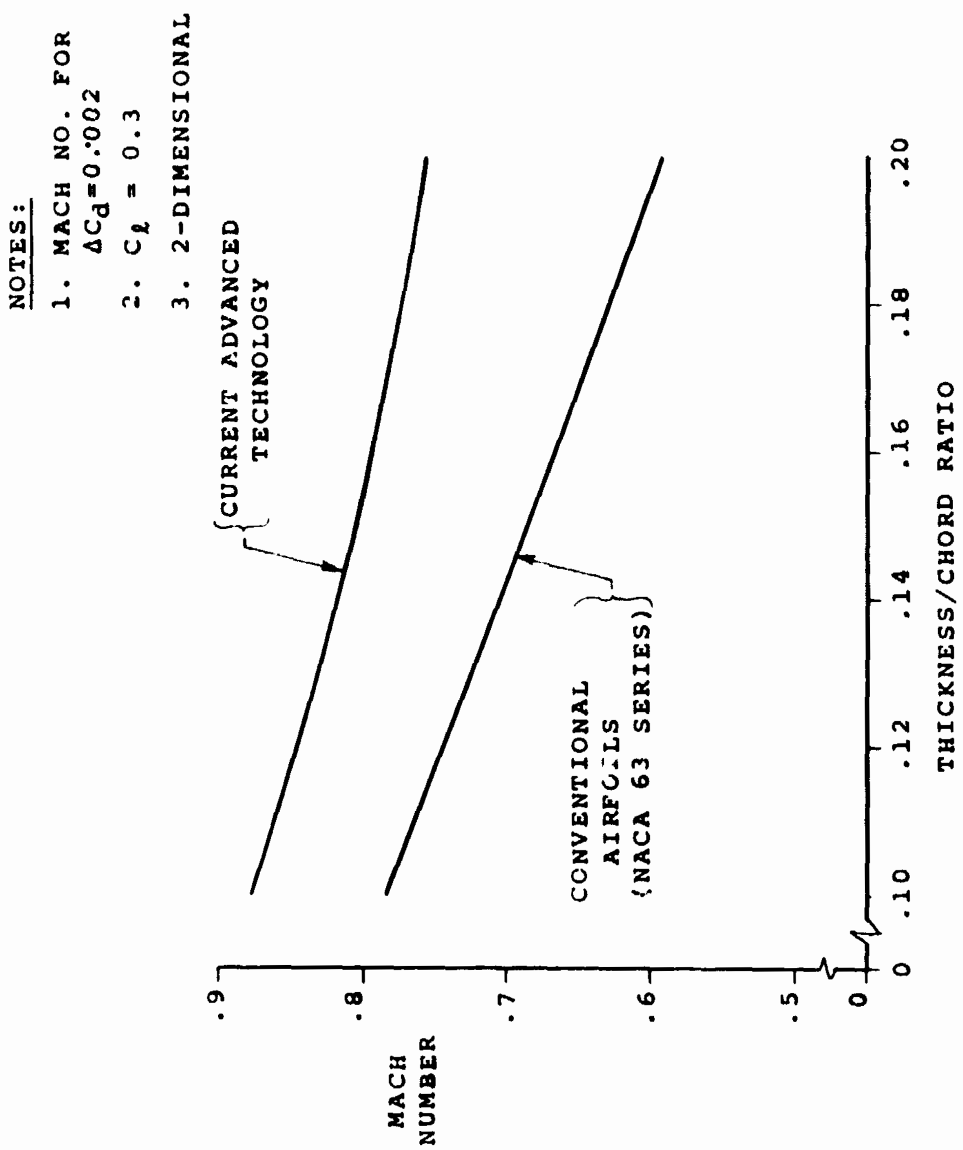


FIGURE 3-2: EFFECT OF AIRFOIL THICKNESS ON DRAG DIVERGENCE MACH NUMBER

with today's advanced technology airfoil. This indicates that a 21% thick section can be used while maintaining a drag divergence Mach number of 0.75, thus meeting the flight requirements for aircraft designed for speeds up to 460 knots. As a result of these considerations, the wing thickness was selected as 21%.

3.2.1.2.3 Wing Loading

A limit is imposed on wing loading by blade loads encountered during conversion (rotor spin up/down, fold/unfold).

During spin-up and spin-down the rotor passes through the one-per-rev resonance crossover where blade loads peak rather sharply.

Reference 12 showed that the two operational parameters which have the most effect on these blade loads are airspeed and angle of attack with the latter being the more powerful. Angle of attack can be reduced either by lowering the flaps or increasing the airspeed. The speed range in which conversion occurs can be lowered by reducing wing loading at a fixed angle of attack.

It was assumed that conversion would nominally take place at a speed of 1.3 V_{STALL}, with variations up to 1.45 V_{STALL}, using maximum effective flap deflection. The conversion speed should also not be less than 1.2 V_{STALL}, flaps up. The following constraints were placed on end-of-conversion speed to

ensure satisfactory blade loads throughout conversion:

a. Nominal conversion at a speed no greater than 175 KEAS

b. Maximum conversion speed, including flight path variations and/or flaps retracted, not to exceed 200 KEAS.

The equivalent airspeeds corresponding to these conditions are plotted versus wing loading in Figure 3-3. The conversion speed criteria result in a maximum wing loading of 109 psf. This was used for the stowed rotor aircraft of this study.

3.2.1.2.4 Wing Aspect Ratio

Increasing the wing aspect ratio, for a given wing area, increases the structural weight required to provide adequate strength:

a) The root bending moment in hover increases due to increased semispan.

b) The wing structural box reduces in size due to both reduced chord and thickness (for constant t/c).

Increased wing structural weight, from strength considerations, is offset by reduced induced drag, and therefore reduced fuel required, as the aspect ratio increases. However, for the tilt

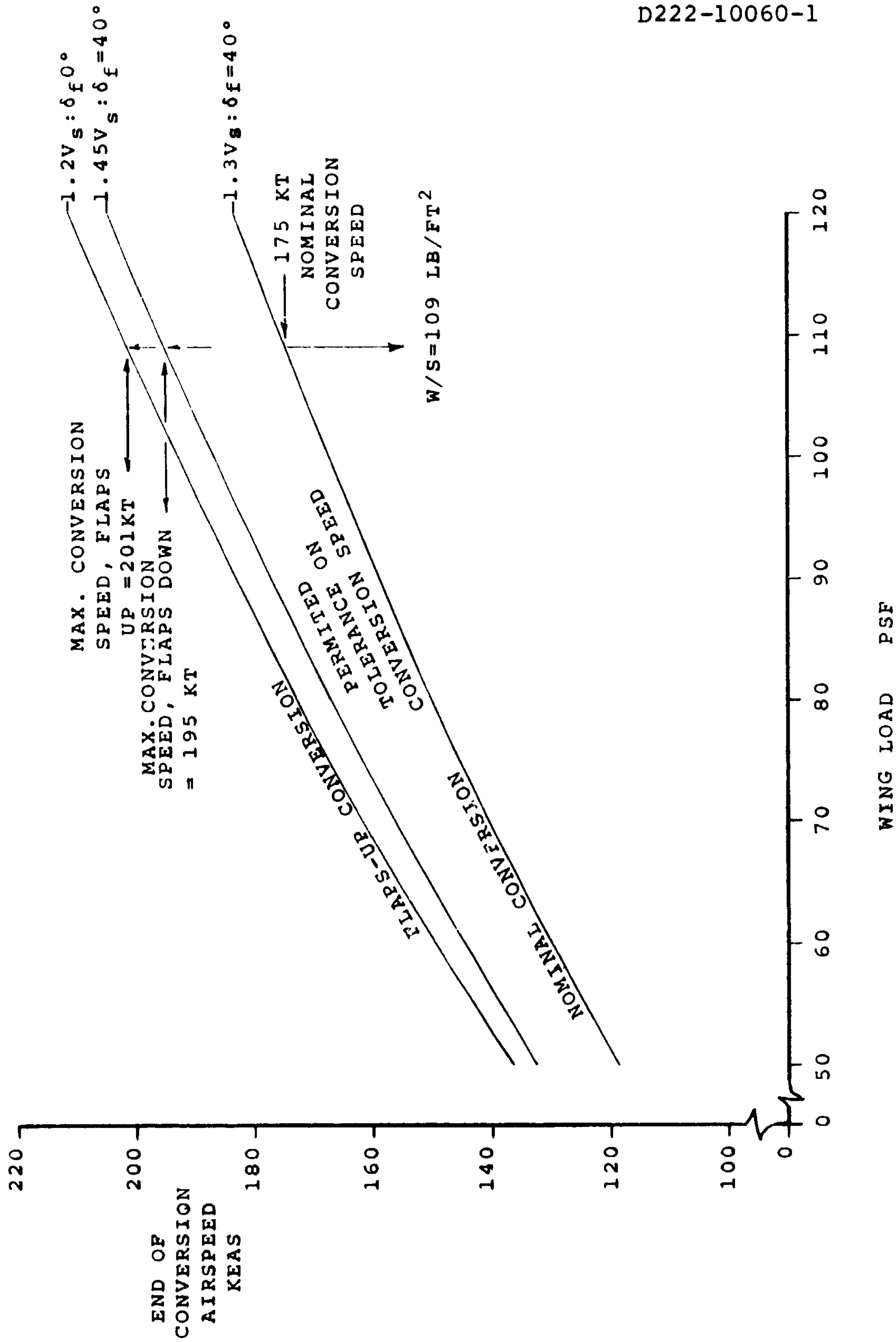


FIGURE 3-3: WING LOADING SELECTION

rotor aircraft, wing stiffness and natural frequency in bending and torsion must be carefully controlled to avoid potential problems with the aeroelastic air resonance and whirl flutter modes. Based on Boeing experience with tilt rotor designs, the aspect ratio was constrained to values less than 8.0 to avoid excess weight penalties from wing frequency considerations.

3.2.1.3 Transmission and Rotor Design

In the study of Reference 1, the transmissions and rotors of the tilt rotor aircraft were structurally designed by the maximum rated horsepower of the engine at the hover rpm. This criterion is somewhat conservative since, for the design mission, the maximum operating torque - which dictates the transmission weight - occurs at the 20,000 ft. cruise condition and the maximum operating power - which is used in the rotor weight trend equations - occurs at the mid-point hover. A reduction in transmission and rotor weight and a corresponding de-escalation of the weight of other structure could have been achieved by designing to the critical operational level of torque and power rather than to the rated level. However, since it simplified the sizing analysis and provided an increased margin of performance at sea level, standard day conditions, the full rated power was used to size the rotors and transmissions.

Applying this criterion to the stowed rotor aircraft of this study however, would impose a significant weight penalty since the rotor transmissions are used only during hover and low

speed flight operations; the cruise fans being used for maximum speed cruise. Therefore, for the stowed rotor aircraft of this study, the transmissions and rotors were designed to accept the maximum operating torque and power, which in all cases occurs at the mid point hover condition.

In order to obtain a valid weight comparison, the tilt rotor aircraft of this study were designed to similar ground rules. As a result, it will be seen that the design point tilt rotor of this study is approximately 8% lighter than the corresponding design from the Reference 1 study. For the tilt rotor aircraft defined here, the transmissions are designed for Military Power at 20,000 ft., standard day conditions and for a rotor speed of 70% hover rpm. This provides a small speed margin relative to the design cruise speed since the design point was dictated by a specified cruise speed at Normal Rated Power. The rotor weights are based on the mid point hover power, T/W=1.1 at 5000 ft., 95°F.

The rotors considered in the study were assumed to be of the same hingeless design as the rotor defined for the Tilt Rotor Research Aircraft in NASA CR-114438, "Preliminary Design of Research Aircraft", Reference 2. The blades are assumed to be rectangular in planform. The same basic design and type of construction was assumed and the same weight factors were used. The only design difference in the case of the stowed rotor was in the incorporation of blade fold mechanisms into

the hub design. Rotor weight factors were adjusted to take this into account.

In Reference 16, Cook and Poisson-Quinton have pointed out that the cruise performance of the low disc loading rotor can deteriorate rapidly with increasing speed at Mach numbers above the design point. However, by designing the rotor specifically for high speed flight, such as use of supercritical airfoils, tailored thickness distribution, etc. it should be possible to retain reasonable cruise efficiencies to Mach numbers approaching 0.7. In order to show the effect of high speed rotor performance on the tilt rotor - stowed rotor tradeoff, two different cruise efficiency vs. Mach number curves were used for the tilt rotor aircraft. These are shown in Figure 3-4. The effect of the assumed rotor cruise performance is discussed in Section 3.2.2.3.

3.2.1.4 Engine Characteristics

3.2.1.4.1 Engine Cycles

The stowed rotor aircraft use convertible fan engines for propulsion in cruise and in hover. These power plants utilize a turboshaft core engine which is geared either to a forward fan in cruise or to the rotors in hover. The manner in which these components are geared together is described in AFFDL-TR-71-62 Volume 1, "Design Studies and Model Tests of the Stowed Tilt Rotor Concept", Reference 5.

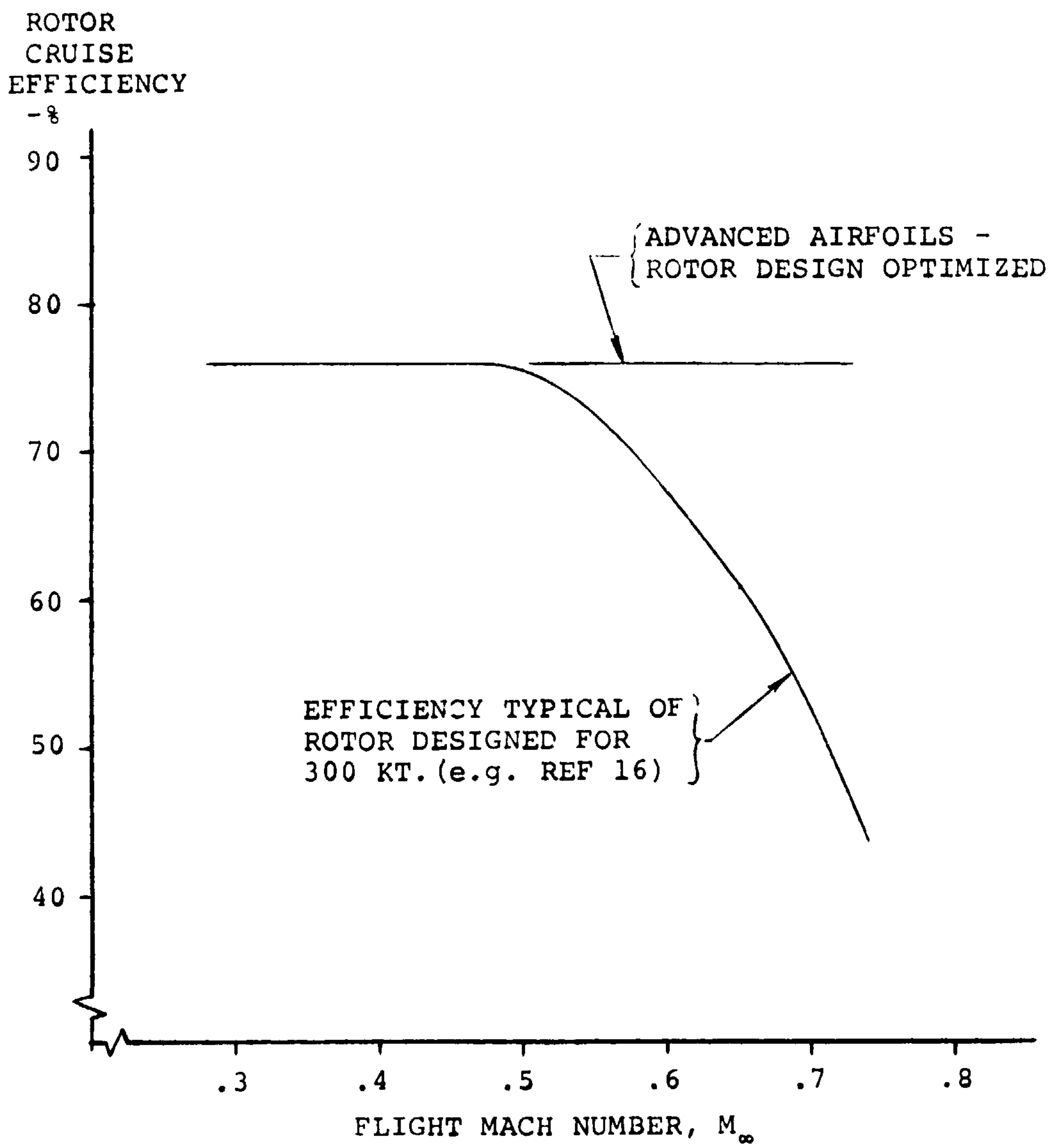


FIGURE 3-4: ROTOR CRUISE PERFORMANCE AT HIGH MACH NUMBER

The convertible engines used in this study were based on the GE TF-34/S1 as a core engine. This engine was combined with a series of forward fans with various bypass ratios. The performance characteristics of the composite engines were then reduced to a referred basis ("rubberized"). The internal logic of the VASCOMP program (used for sizing and performance analysis) converted the engine from a thrust-producer in cruise to a power-producer in hover.

A conventional turboshaft engine geared to the rotors is used to power the tilt rotor aircraft. The engine cycle used for the tilt rotor aircraft in this study is based on Lycoming PLT-27 technology. Again, the characteristics of the engine have been "rubberized" or reduced to a referred basis.

Although different engines were used for the stowed rotor and tilt rotor, the TF-34 and PLT-27 engines represent the same level of technology based on comparable values of pressure ratio, turbine inlet temperature, specific fuel consumption and specific power.

3.2.1.4.2 Bypass Ratio Selection

An early task in the study was to determine the optimum fan bypass ratio for the stowed rotor aircraft. A configuration study was done in which wing loading varied from 80 to 120 psf, disc loading varied from 10 to 15 psf, and engine bypass ratio varied from 2 to 10.

The resulting trends of design gross weight with disc loading and bypass ratio are shown in Figure 3-5 for the limit wing loading (109 psf) and the 400 kt design speed. The trends shown are fairly typical of those obtained at other design speeds between 300 and 500 knots.

All of the design ground rules described in this section were observed with the exception that the transmission torque limit was not applied. (This was a design refinement incorporated later in the study.) As a result, the design gross weights obtained do not match those obtained in the latter part of the study. The trends shown are still considered to be valid, however,and a bypass ratio of 4 was used in sizing the stowed rotor design point aircraft.

A similar study was done to investigate the effect of bypass ratio on engine performance. Cruise thrust was computed for normal power at 20,000 ft/STD for various bypass ratios for a representative gas generator of 2500 horsepower rating. These data are shown in Figure 3-6. The results indicate that the bypass ratio for maximum engine performance decreases as speed increases.

A cross-plot of thrust versus bypass ratio at the 400 kt stowed rotor design speed is shown in Figure 3-7. These results lend further support to the selection of 4.0 as the design bypass ratio for the stowed rotor design point SAR aircraft.

NOTES:

1. Constant Wing Loading = 109PSF
2. USAF-SAR HI-HI Mission Profile
3. Constant Airspeed

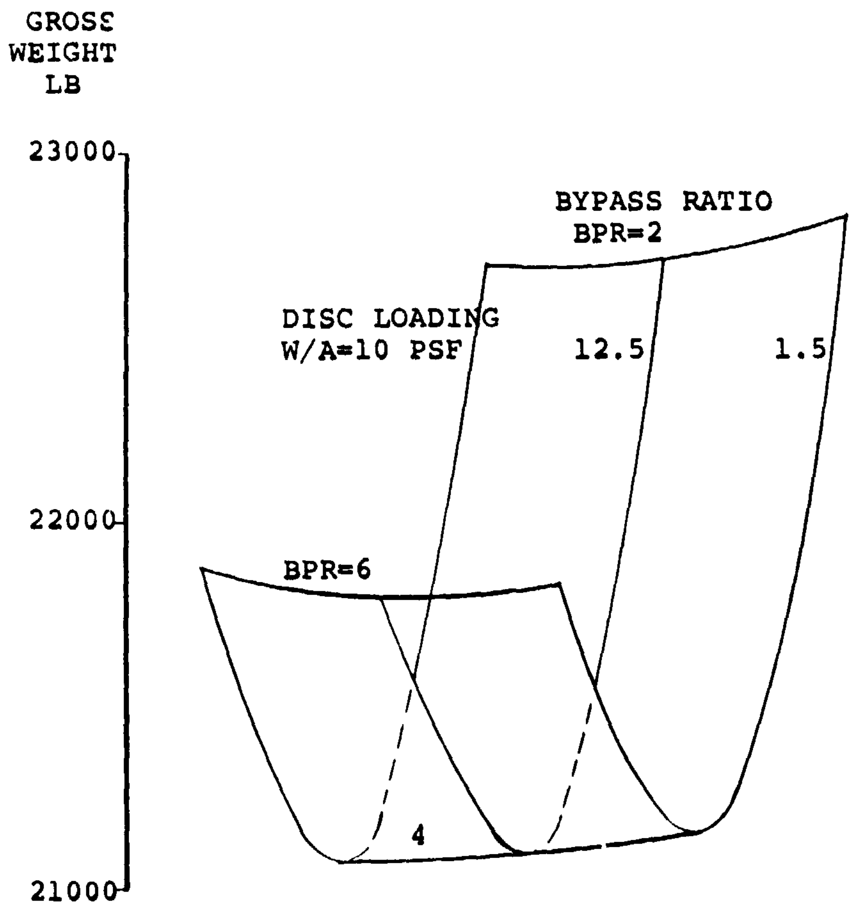


FIGURE 3-5: ENGINE BYPASS RATIO TRADE STUDY - GROSS WEIGHT DUE TO BYPASS RATIO AND DISC LOADING

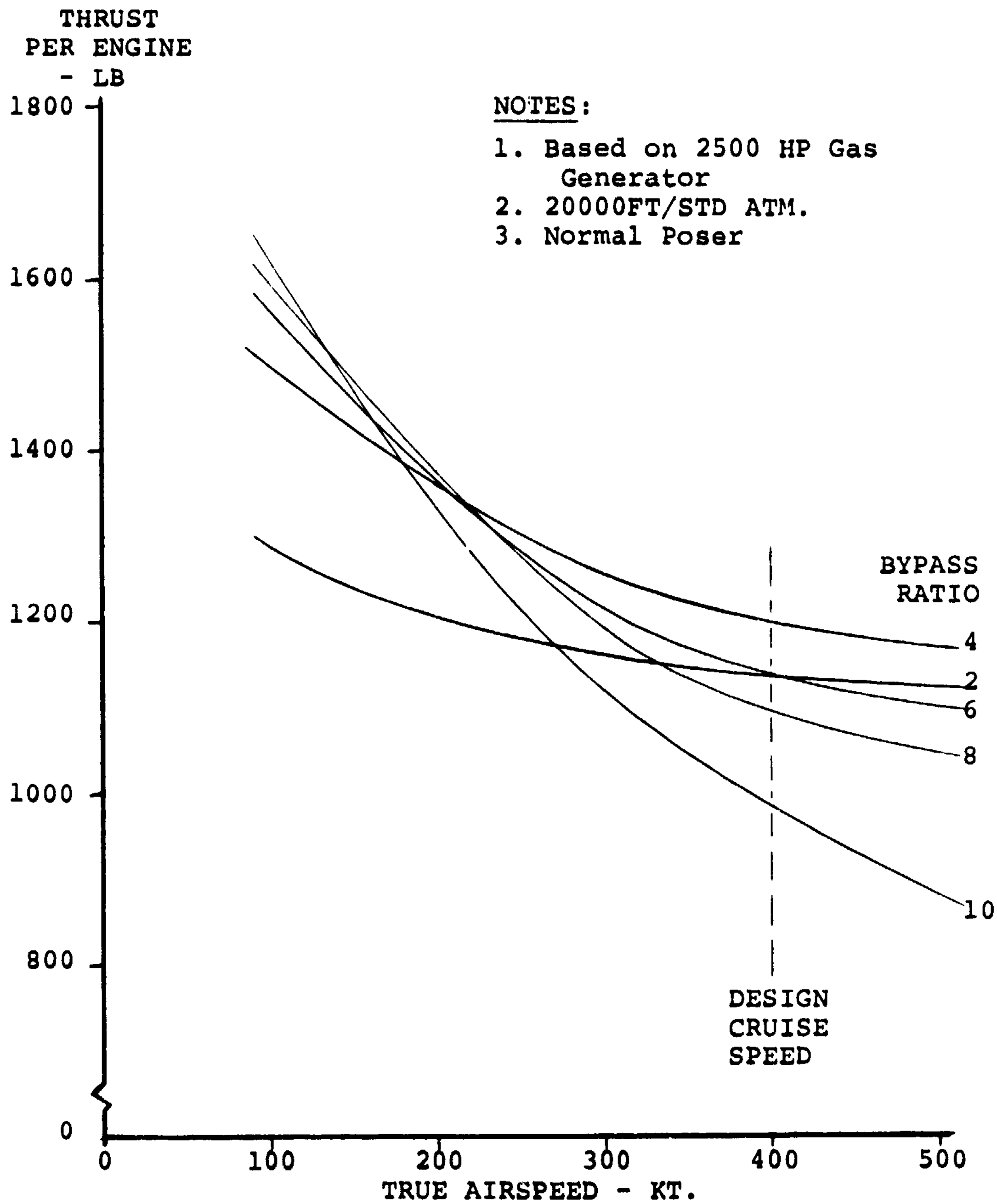


FIGURE 3-6: ENGINE BYPASS RATIO TRADE STUDY - THRUST AVAILABLE VS TRUE AIRSPEED

NOTES:

1. V=400 KTAS
2. 20000 FT/STANDARD TEMPERATURE

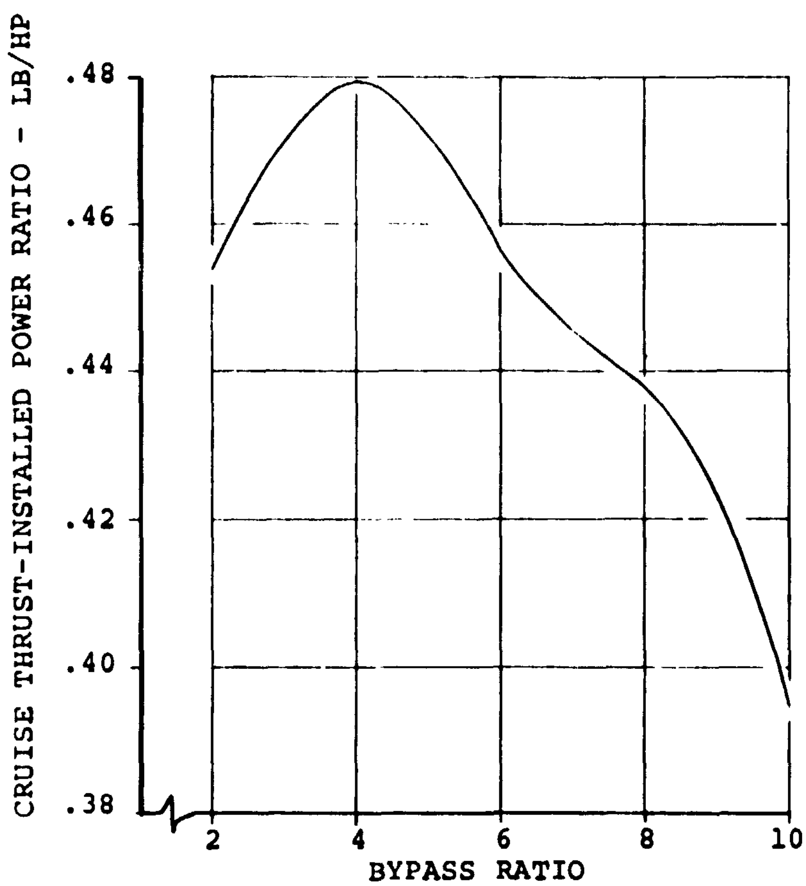


FIGURE 3-7: ENGINE BYPASS RATIO TRADE STUDY -CRUISE THRUST PER RATED HORSEPOWER VS BYPASS RATIO

3.2.1.5 Aircraft Drag

Simplified drag models were used for both the stowed and tilt rotor aircraft. These models represent the drag of the aircraft as simple linear functions of wing area. The methods of Boeing Document D8-2194-1, "Drag Estimation of V/STOL Aircraft", Reference 13, were used to calculate the intercept and slope of the trend curves.

The drag trends used are shown in Figure 3-8a. The tilt rotor trend is identical to that presented in NASA CR-114437, "Conceptual Design of Useful Military and/or Commercial Aircraft", Reference 1. The stowed rotor drag trend was developed in a similar manner for the aircraft exclusive of the engine nacelles. Size trends were developed which gave nacelle length, diameter, and wetted area as a function of bypass ratio and rated thrust. These size trends were used to develop engine nacelle Δf_e curves as shown in Figure 3-8b.

3.2.1.6 Criteria for Selecting Design Point Aircraft

3.2.1.6.1 Stowed Rotor Aircraft

The stowed rotor aircraft were sized to meet the mission requirements described in Section 3.2.1.1. In addition, the following design constraints were imposed:

1. Thrust-weight ratio capability at the mission mid-point of at least 1.1 with seven (7) rescuees aboard (See Section 3.2.1.1).

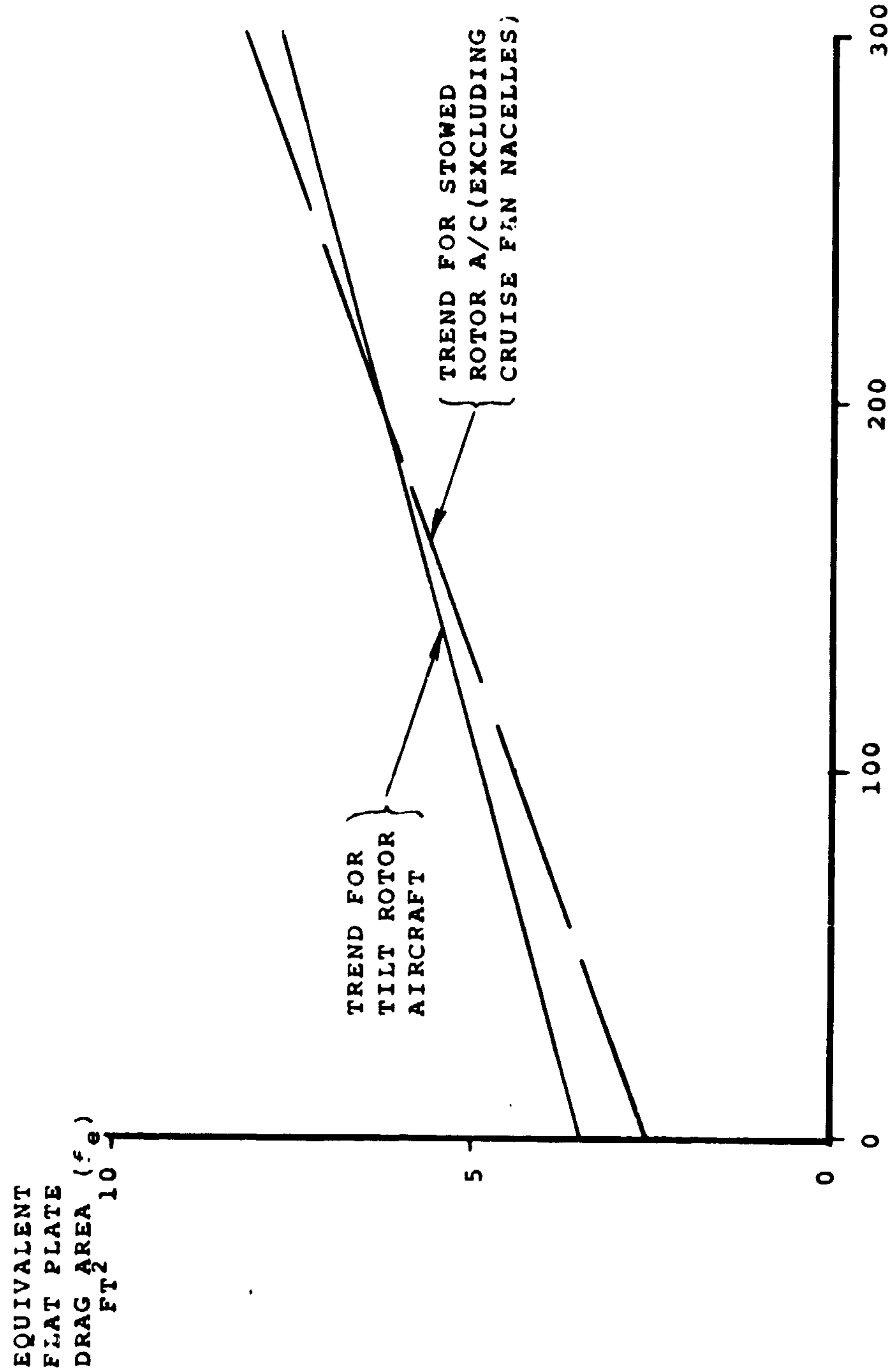


FIGURE 3-8a: DRAG TRENDS

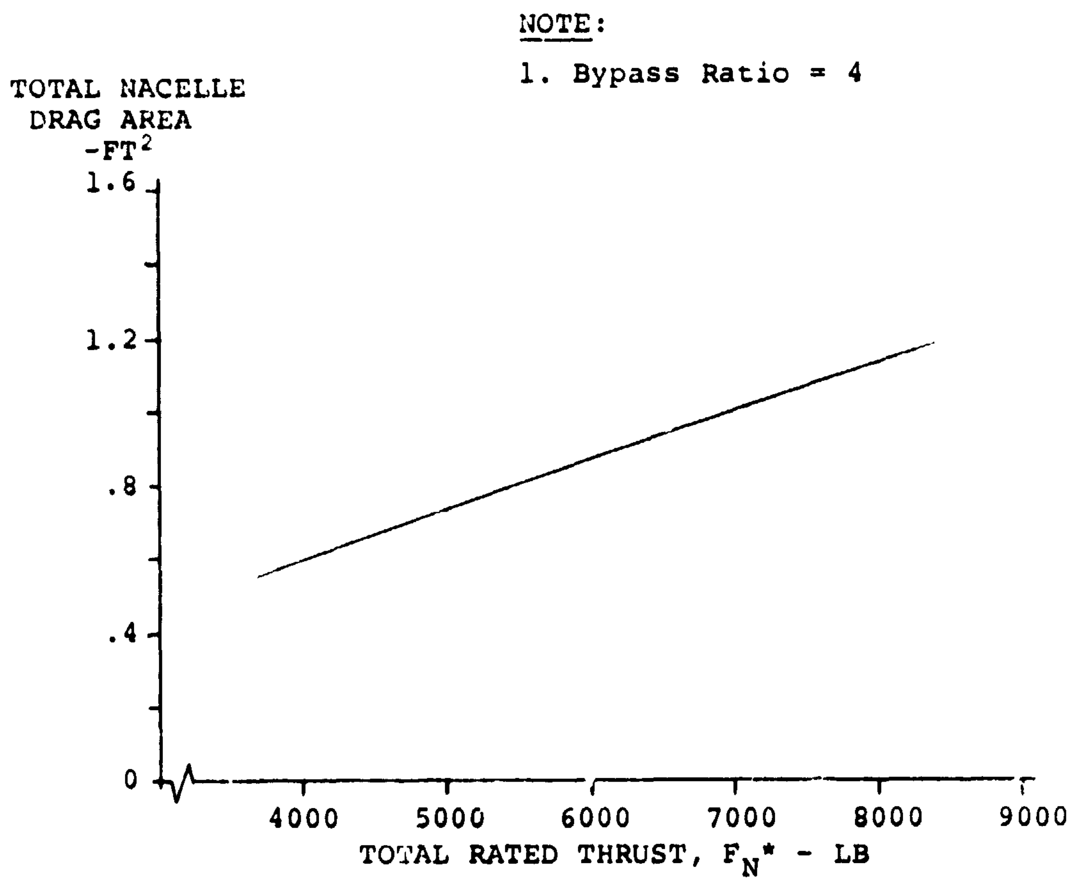


FIGURE 3-8b: STOWED ROTOR AIRCRAFT ENGINE NACELLE DRAG TREND

2. Maximum hover disk loading of 15 psf.
3. Rotor solidity greater than .058.
4. Wing loading less than 109 psf. } See Section 3.2.1.2
5. Wing aspect ratio less than 8. }

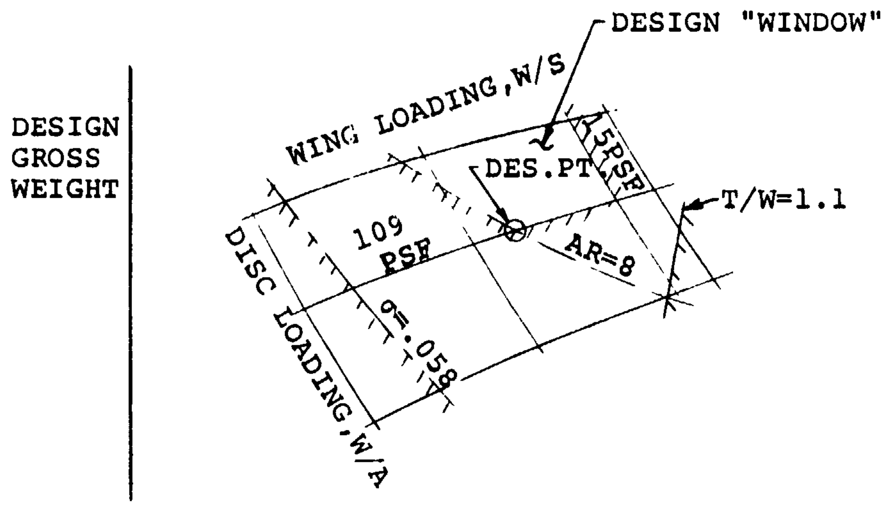
In general, these constraints are the result of practical considerations in the design of tilt/stowed rotor aircraft. The disc loading limit, for example, was imposed to avoid excessive downwash velocities in hover. Downwash velocity immediately below the rotor is directly related to disc loading. At high disc loadings, the resulting high downwash velocities would tend to hamper rescue operations.

A maximum thrust coefficient to solidity ratio, C_T/σ, of 0.135 was used, based on rotor stall flutter considerations. However, in no event was the solidity permitted to fall below a value of 0.058.

This limit is based on practical design and manufacturing considerations related to blade torsional and flapping stiffness requirements. As rotor blades become narrower and thinner at the lower solidities it becomes more and more difficult to tune them and still meet design fatigue life requirements.

The stowed rotor aircraft defined in the study are, in general, defined by the intersection of two boundaries defined by the constraints enumerated above (although there may be "triple points" at which three constraint conditions coincide). This

is shown in the sketch below which illustrates the manner in which the various constraints influence the design point selection.



This figure is a carpet plot of design gross weight versus wing loading and disc loading at a specified cruise speed. The boundaries defined by the constraints are superimposed on it and define a design "window" in which design points are allowed. The design point aircraft is selected at the boundary intersection that gives the lowest design gross weight.

3.2.1.6.2 Tilt Rotor Aircraft

The tilt rotor aircraft were sized to the same mission requirements as the stowed rotor aircraft (Section 3.2.1.1). Additionally, the following design constraints were imposed.

1. Thrust-weight ratio capability at the mission mid-point of at least 1.1 with seven rescuees aboard (See Section 3.2.1.1).
2. Maximum hover disc loading of 15 psf
3. Rotor solidity greater than .058
4. Wing chord to rotor diameter ratio of 0.2

A different wing design constraint is used for the tilt rotor aircraft because it is rotor-driven in cruise and the wing must be configured to avoid static divergence and whirl flutter. Specifying chord to diameter ratio is equivalent to specifying wing aspect ratio. This is because wing span is directly related to rotor diameter (b=DIA + 7.5') and chord is also directly proportional to diameter when the chord/diameter ratio is fixed. As a result, the aspect ratio varies between 6.5 and 6.0 for a range of diameter between 25 feet and 37.5 feet. Previous design experience has shown that a chord-diameter ratio of 0.2 gives aspect ratios in the range required to adequately control these modes without excessive weight penalties. With wing configuration fixed in this manner, wing loading becomes a function of disc loading. Therefore, rotor diameter becomes the design parameter. The procedure for selecting the design point aircraft then became a matter of sizing aircraft for a series of rotor diameters and determining the minimum weight configuration corresponding to the most critical of the first three design constraints.

3.2.2 DESIGN POINT SELECTIONS

3.2.2.1 Stowed Rotor

For each design cruise speed, a parametric family of stowed rotor aircraft were sized to meet the mission requirements discussed in Section 3.2.1.1. Each design point in this family of aircraft was defined by a specific combination of wing loading and disc loading. An example of the results, in terms of design gross weight and required power, is shown in Figures 3-9 and 3-10 for a design cruise speed of 400 knots. Shown as overlays on these carpet plots are curves representing the limiting values of each of the five design constraints. It is seen that the lightest aircraft, for the 400 knot design cruise speed, is defined by the combination of aspect ratio and wing loading limits. This point also corresponds to the lowest required gas producer power. Design gross weight is 19070 pounds and power required is 2455 horsepower per engine. The rotor diameter is 30.3 feet and disc loading is 13.3 psf.

3.2.2.2 Tilt Rotor

For the tilt rotor, at each design cruise speed, the effect of rotor diameter on the important aircraft performance and design characteristics was evaluated as shown in Figure 3-11. For the 300 knot design condition, as shown in this figure, the design point is dictated by the maximum disc loading constraint (15 psf). Lighter aircraft could be achieved by using smaller

NOTES:

1. Aircraft sized to USAF-SAR HI-HI Mission
2. Design Criteria
   a. $(T/W)_{MP} \geq 1.1$
   b. $AR \leq 8.0$
   c. $W/A \leq 15$ LBS/FT^2
   d. $W/S \leq 109$ LBS/FT^2
   e. $\sigma \geq .058$
3. V_{CRUISE} = 400 KTAS
4. By-pass Ratio = 4

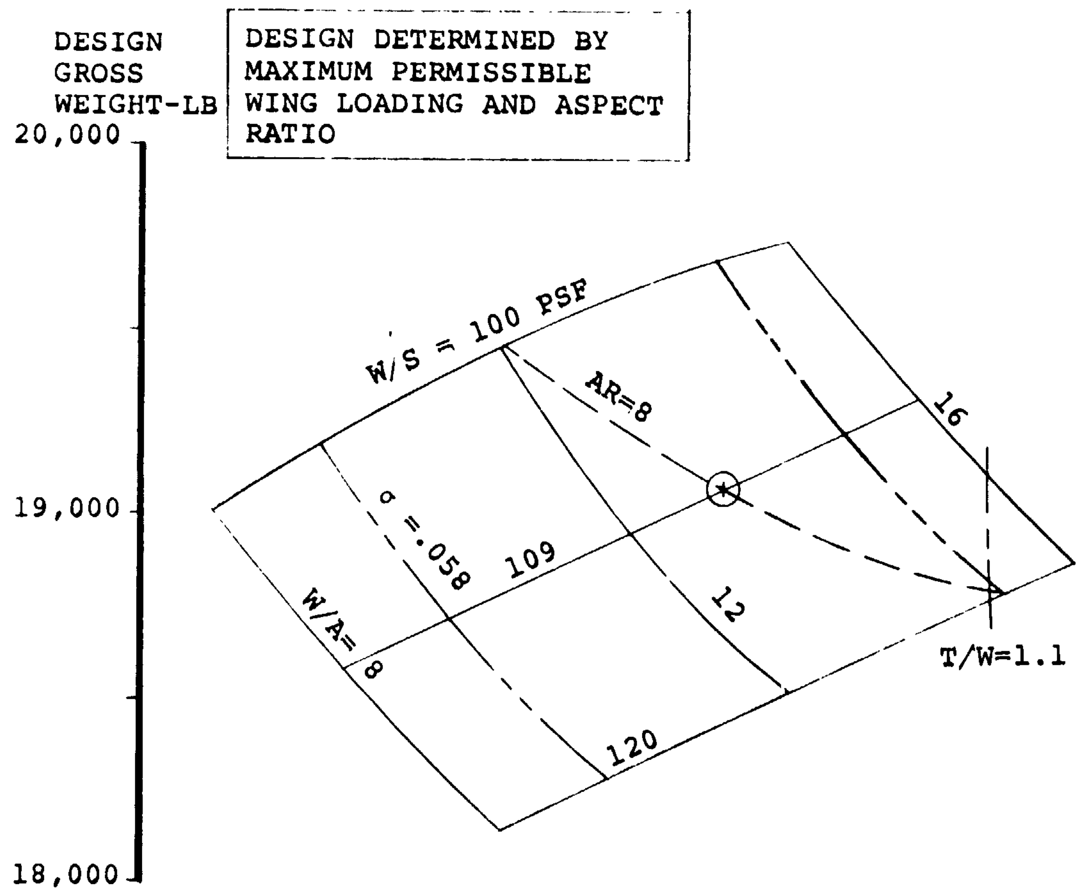


FIGURE 3-9: EFFECT OF DESIGN PARAMETERS ON STOWED ROTOR GROSS WEIGHT

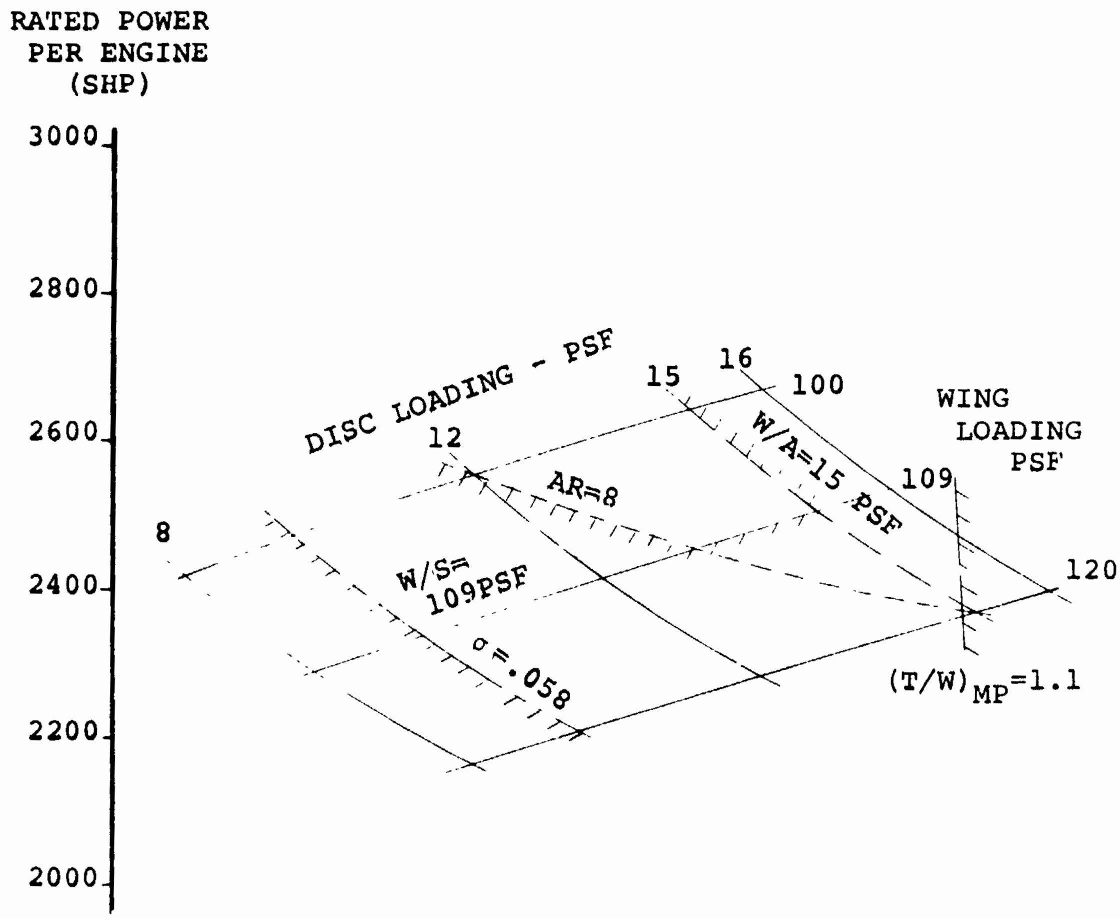


FIGURE 3-10: EFFECT OF DESIGN PARAMETERS ON STOWED ROTOR INSTALLED POWER

diameter rotors, but this would require disc loadings greater than 15 psf. It is seen that, for this speed, the mid point hover and the cruise requirements are nearly matched, with the mid point thrust to weight ratio (T/W=1.12) being just greater than the minimum required value of 1.10. The design point aircraft has a design gross weight of 15630 pounds and a rotor diameter of 25.8 feet. Although not shown, the installed engine power is 1846 shp/engine. The difference in size between this aircraft and the design point SAR of Reference 1 (WT = 16970 lb., DIA = 27.0 ft.) is directly attributable to the different ground rules for transmission and rotor structural design (See Section 3.2.1.3).

The difference in disc loading for the stowed rotor (13.3 psf) and the tilt rotor (15 psf) is due to the difference in permissible aspect ratio. The tilt rotor wing, designed by chord to diameter ratio of 0.2, has an aspect ratio of 6.5. Had aspect ratio been permitted to increase to a value of 8.0, as on the stowed rotor, the design point diameter would have increased with an accompanying reduction in disc loading. The mid-point hover thrust to weight ratio would have been the design parameter.

3.2.2.3 Comparison of Stowed Rotor and Tilt Rotor Design Point Aircraft

Stowed rotor and tilt rotor aircraft were sized at design cruise speeds across the speed range from 300 to 450 KTAS. As

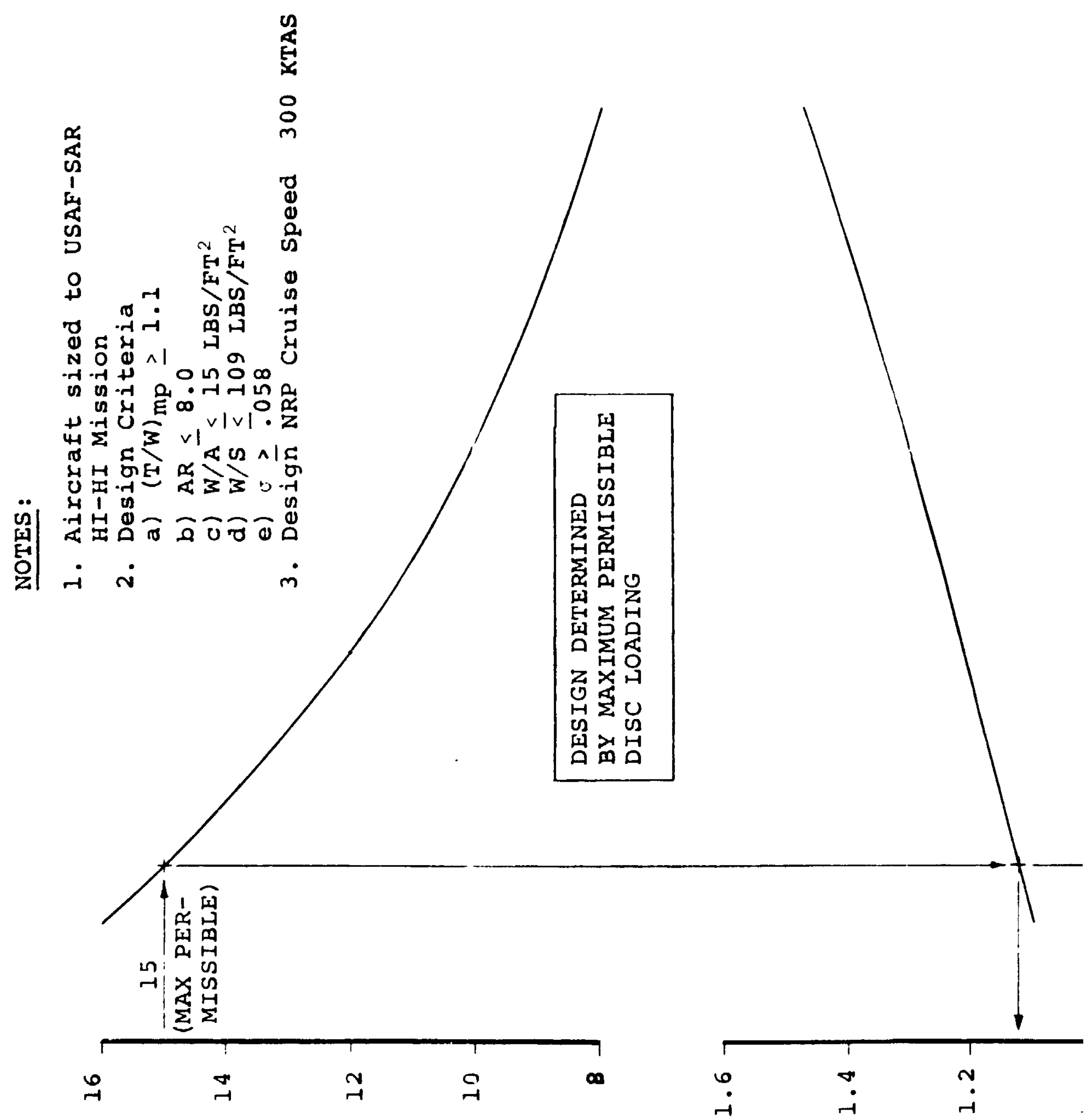


FIGURE 3-11: EFFECT OF ROTOR DIAMETER PARAMETERS

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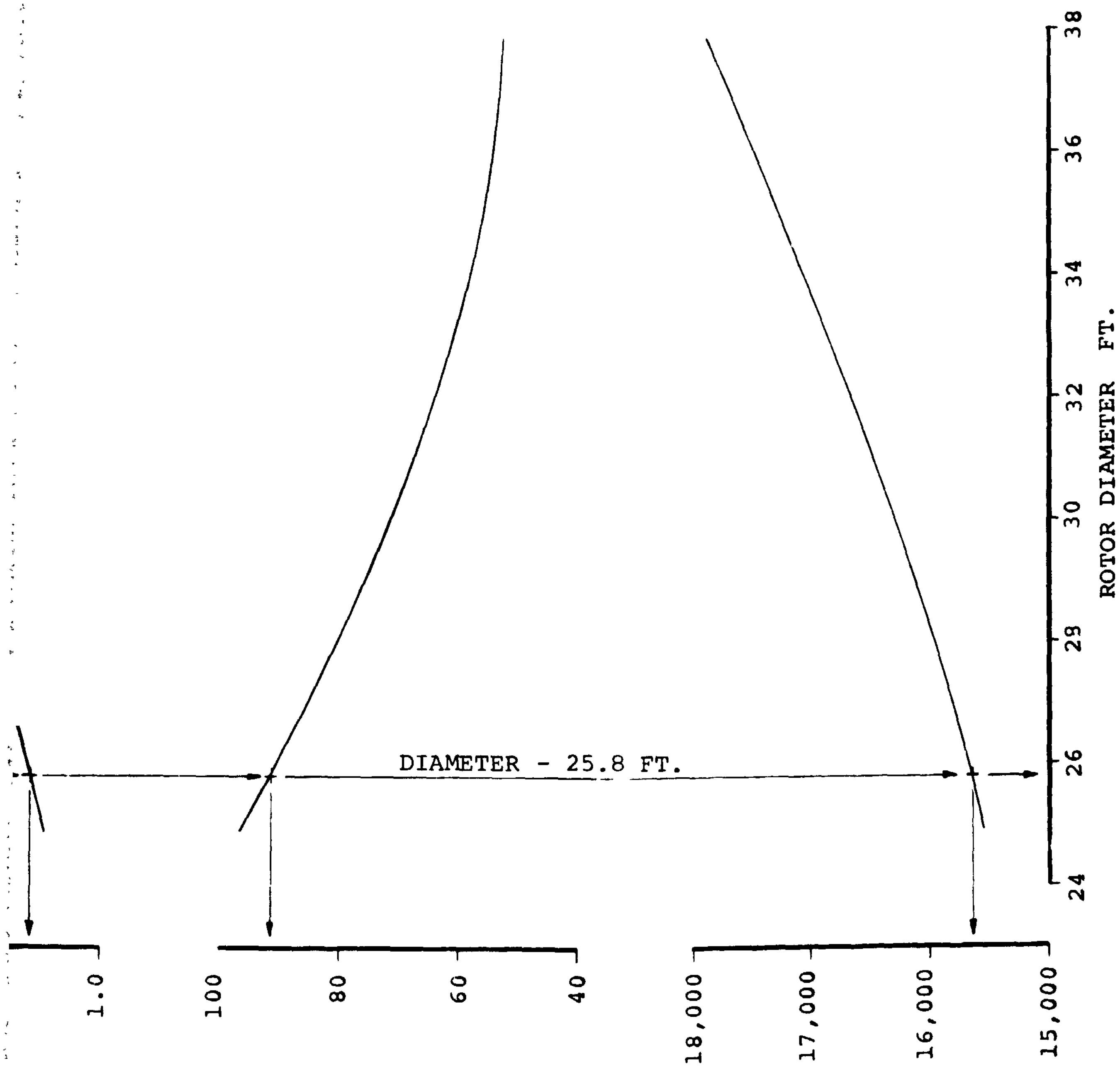

AMETER ON TILT ROTOR SIZE

a result it is possible to show the weight penalties incurred by increasing design speed and also to determine the crossover point at which the stowed rotor is more economical than the tilt rotor.

The stowed rotor and tilt rotor aircraft obtained are shown for comparison in Figure 3-12. For the tilt rotor, the effect of rotor cruise efficiency is shown, corresponding to the two different η_{CR} trends of Figure 3-4. The aircraft at points along each of the curves are minimum weight aircraft consistent with the design constraints described in Section 3.2.1.6. For example, for the tilt rotor aircraft it was found that increasing the disc loading by reducing rotor diameter led to an overall reduction in gross weight and power required. However, since the disk loading is limited to 15 psf, the lightest permissible aircraft was defined by the limit disc loading (See Figure 3-11).

In general, both types exhibit a rapid weight increase with increasing design speed. For the tilt rotor this rapid increase begins at about 296 KTAS. For the stowed rotor the rapid weight increase begins at 388 KTAS. It is at these points that the aircraft have evenly matched hover and cruise power requirements. That is, the installed power is just sufficient to enable the aircraft to cruise at the specified speed and to meet the hover thrust-weight ratio requirement at the midpoint.

For the tilt rotor aircraft the match-point occurs at 296 KTAS. For design speeds greater than this, it is necessary to observe the restriction on disc loading. Consequently, all the aircraft in this range have midpoint hover thrust-to-weight ratio values in excess of 1.1. All of the tilt rotor aircraft designed for cruise speeds below 296 KTAS have matched hover and cruise power requirements. However, design disc loading decreases as speed decreases.

For the stowed rotor, the power-match point occurs at 388 KTAS with the optimum combination of design parameters being aspect ratio of 8 and wing loading of 109 psf. For speeds below 388 knots, it is more desirable to reduce wing loading than aspect ratio. The aspect ratio is held at a value of 8.0 and mid-point thrust to weight capability is held at a value of 1.1. As was true with the tilt rotor, as speed is reduced, the design disc loading for the stowed rotor reduces. Finally, when design speed for the stowed rotor is reduced to 329 KTAS, the limiting value for solidity is reached (σ=.058). For speeds below 329 knots, in order to maintain the solidity and thrust to weight limits, it is necessary to reduce aspect ratio below the value of 8.0, and design gross weight begins to increase.

The gross weight crossover for the two configurations occurs at 359 KTAS, when the rotor on the tilt rotor aircraft is designed for high speed flight. Above this speed the stowed

rotor is lighter while the tilt rotor is the ligher configuration for speeds below 359 knots.

From these curves, design point aircraft were selected for each configuration type. These points were selected on the basis of proximity to the hover-cruise match points where gross weight first starts to increase rapidly. The design characteristics of each are discussed in Section 3.3.

Although the effects of rotor cruise efficiency for the tilt rotor are shown on Figure 3-12, it should be noted that it is unrealistic to assume that a 300 knot rotor would be applied to aircraft designed for higher speed operation. By designing the rotor specifically for high speed flight it should be possible to approach the capabilities defined by the curve labeled "optimized rotor design". Since the design point aircraft was picked for 300 knot cruise flight, these considerations are more academic than real.

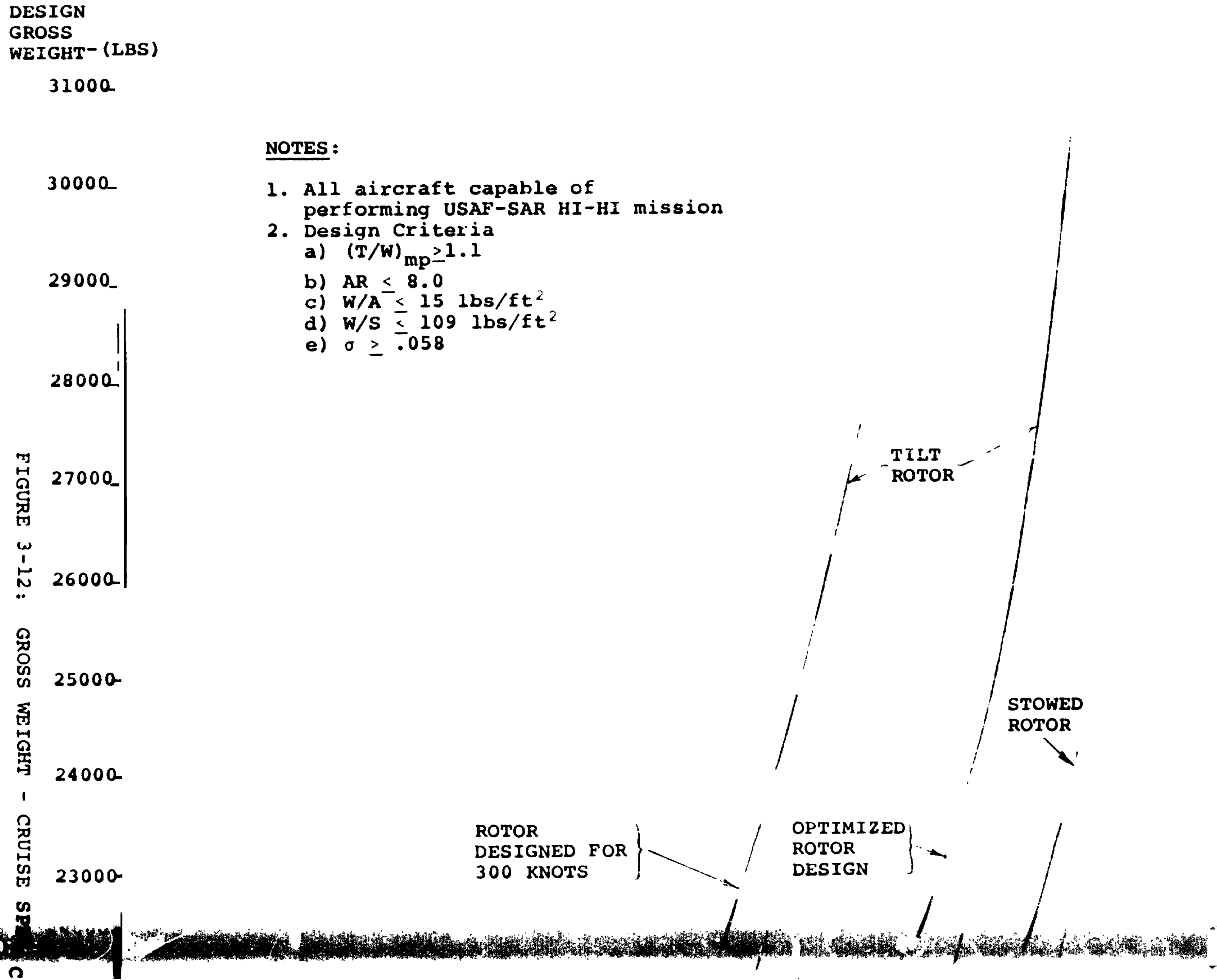

FIGURE 3-12: GROSS WEIGHT - CRUISE SP[illegible]C

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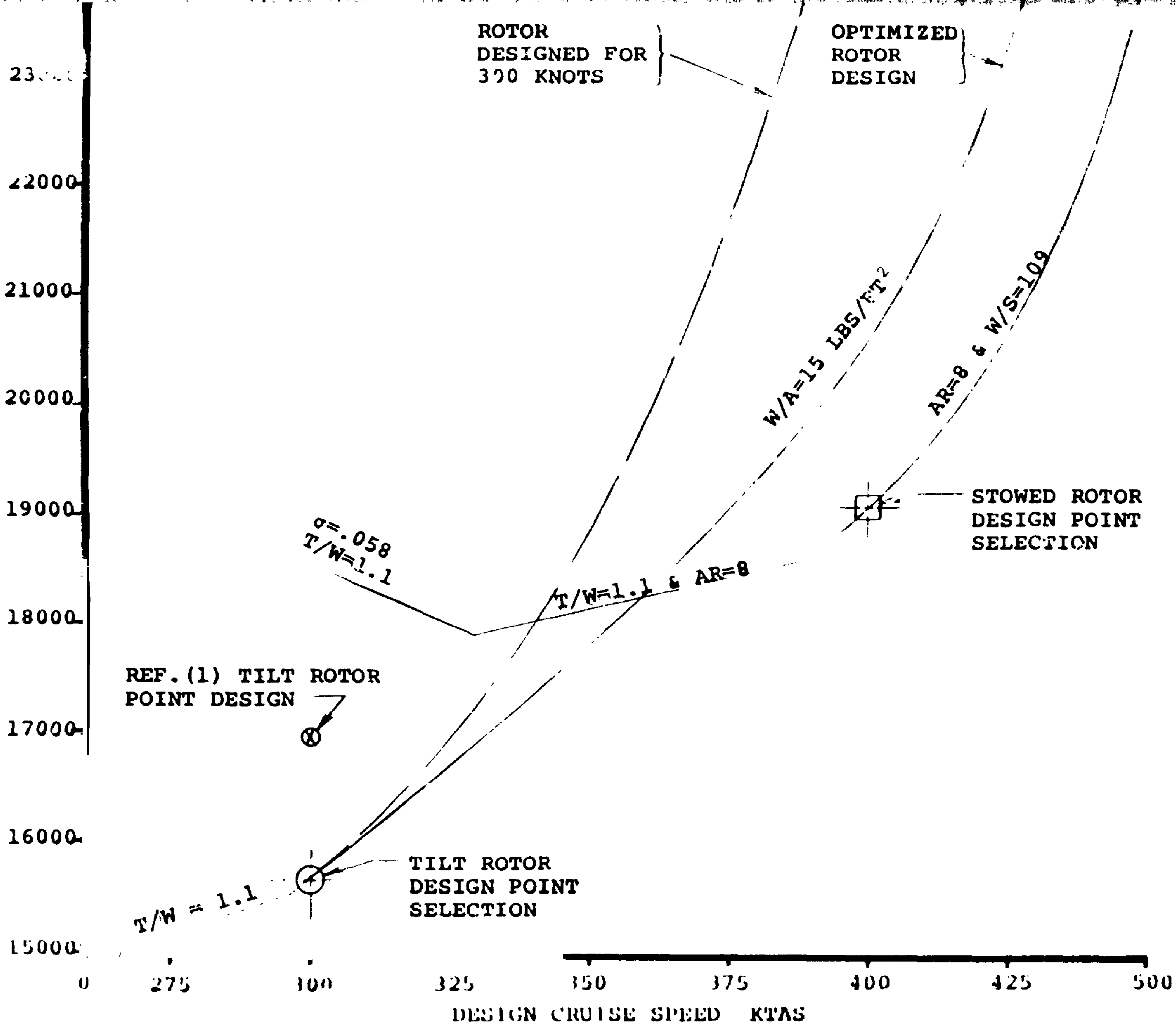


CRUISE SPEED TRENDS

FOLDOUT FRAME 2

3.3 AIRCRAFT DESCRIPTIONS

3.3.1 CONFIGURATIONS AND DESIGN DESCRIPTION

3.3.1.1 Stowed Rotor SAR Aircraft

The design point Stowed Rotor SAR aircraft is shown in three-view in Figure 3-13. The aircraft is quite conventional in layout with the exception of the stowable rotor pods mounted on the wing tips. The aircraft can either be flown in the V/STOL mode with rotor blades deployed or as a conventional airplane with rotor blades folded. The aircraft can be flown as a CTOL but would require takeoff distances of the order of 5000 ft.

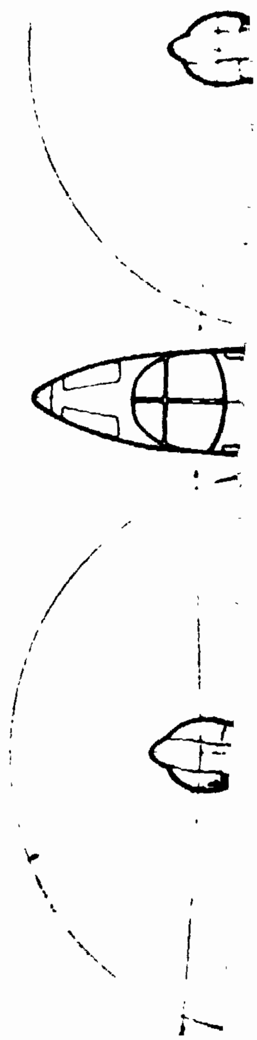
The soft-in-plane hingeless rotors are designed to be stowed for high speed forward flight. The soft-in-plane rotor provides excellent flying qualities characteristics in the V/STOL mode as well as freedom from aeroelastic problems. In flight, the rotors tilt from hover position (rotor disc horizontal) to cruise position (rotor disc vertical). From cruise position, each rotor blade folds around a hinge on the hub to a position flush with the nacelle fairing for a reduction of drag in forward flight.

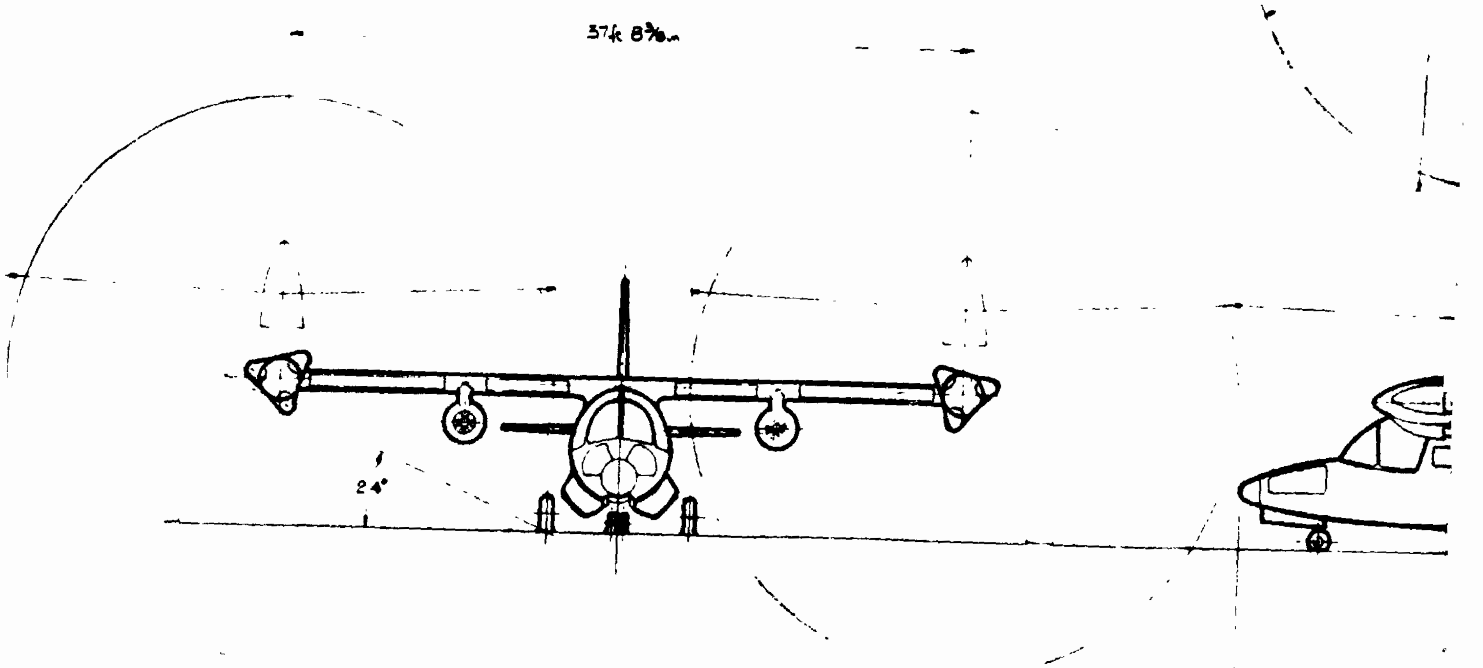
The blade folding kinematics diagram is shown in Figure 3-14. This figure illustrates the end position of the folded blades relative to the wing and the applicable geometry. Figure 3-15 depicts the rotor hub arrangement.

The folding sequence is as follows: with the rotor deployed in the hover mode, transition to the cruise mode is effected by tilting the rotor system until the rotor disc is in the vertical plane. The cruise fan is then clutched on-line and brought up to speed. Power is transferred from the rotors to the cruise fans until the fans are brought up to cruise thrust. The rotor is then declutched and collective pitch reduced until the rotors windmill. Collective pitch is then run through the profile required to stop the rotor, through the feather position, to a position that applies a negative torque to the rotor. When the rotor stops and begins to turn slowly in the opposite direction the opposite rotation is sensed by a mechanism which trips the index latch. This latch locks the rotor into position for folding when the slowly rotating rotor arrives at the index point. (This indexing mechanism is similar to the installation on the CH-46).

With the rotor now positioned, the fold operation automatically begins. The fold actuator system is hydraulically pressurized, releasing the positive piston lock which in turn transfers pressure to the servo system. This moves the piston forward, releasing the forward positional lock on the hub barrel. The blade and hub barrel, pulled by the fold link, begins to rotate around the hinge pivot point. The swashplate actuators are programmed to pitch the blades during folding so that the blades lie flush to the nacelle fairing at the completion of stowing. A sensor identifies the completed fold, engages a

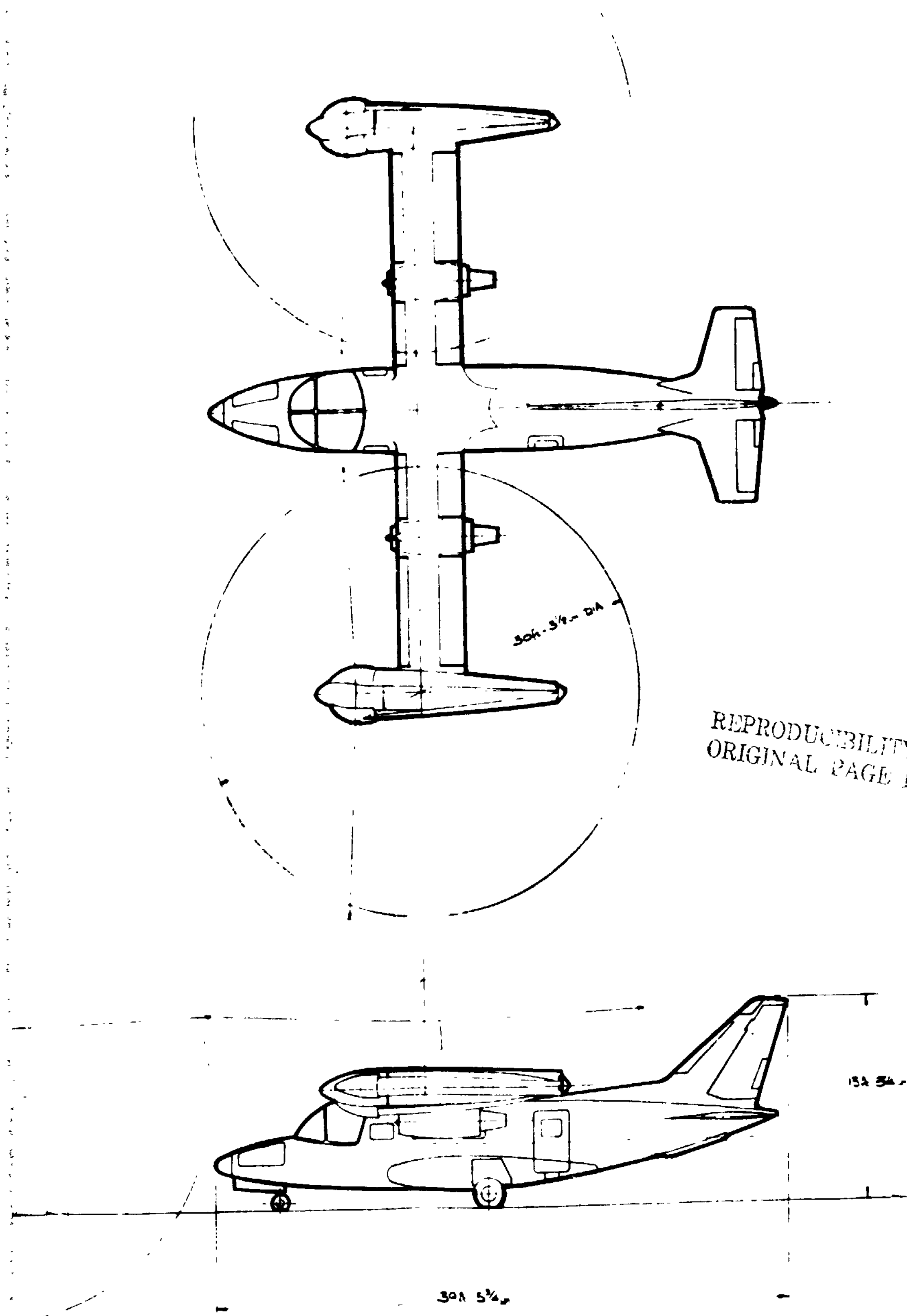
WING	
SPAN	37ft - 8 3/8 in
CHORD	4ft - 7 1/4 in
AREA	175 sq ft
ASPECT RATIO	8.13
TAPER RATIO	1.00
THICKNESS CHORD RATIO	.21
WING LOADING	108 lb sq ft
HORIZONTAL TAIL	
SPAN	12ft 1 in
AREA	39.4 sq ft
VERTICAL TAIL	
SPAN	8.6ft
AREA	41.5 sq ft
ROTOR	
DIAMETER	30ft 3 in
SOLIDITY	.081
DISC LOADING	13.3 lb/sq ft
Nº BLADES	3
WEIGHTS	
DESIGN GROSS WT	19,070 LBS
WT EMPTY	12,423 LBS





FOLDOUT FRAME

FIGURE 3-13: USAF SAR STOWED ROTOR AIRCRA[FT]
3-VIEW



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FOLDOUT FRAME 2

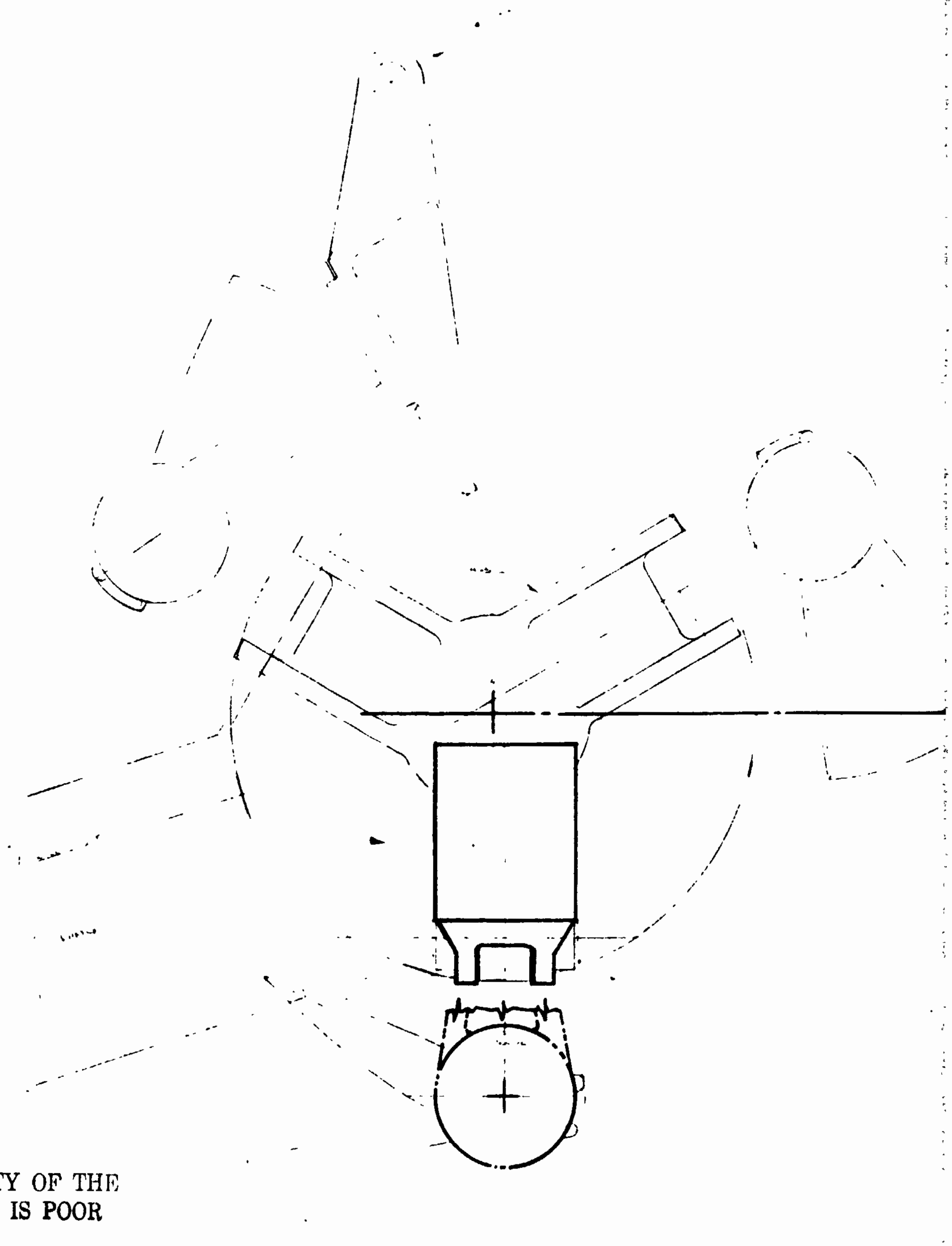

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FIGURE 3-14: BLADE FOLD

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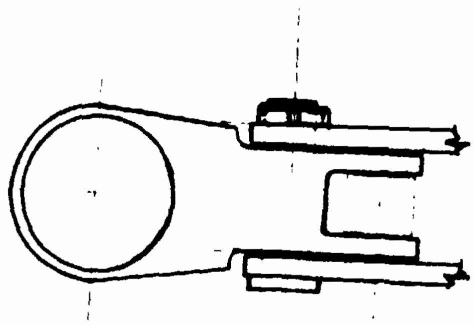

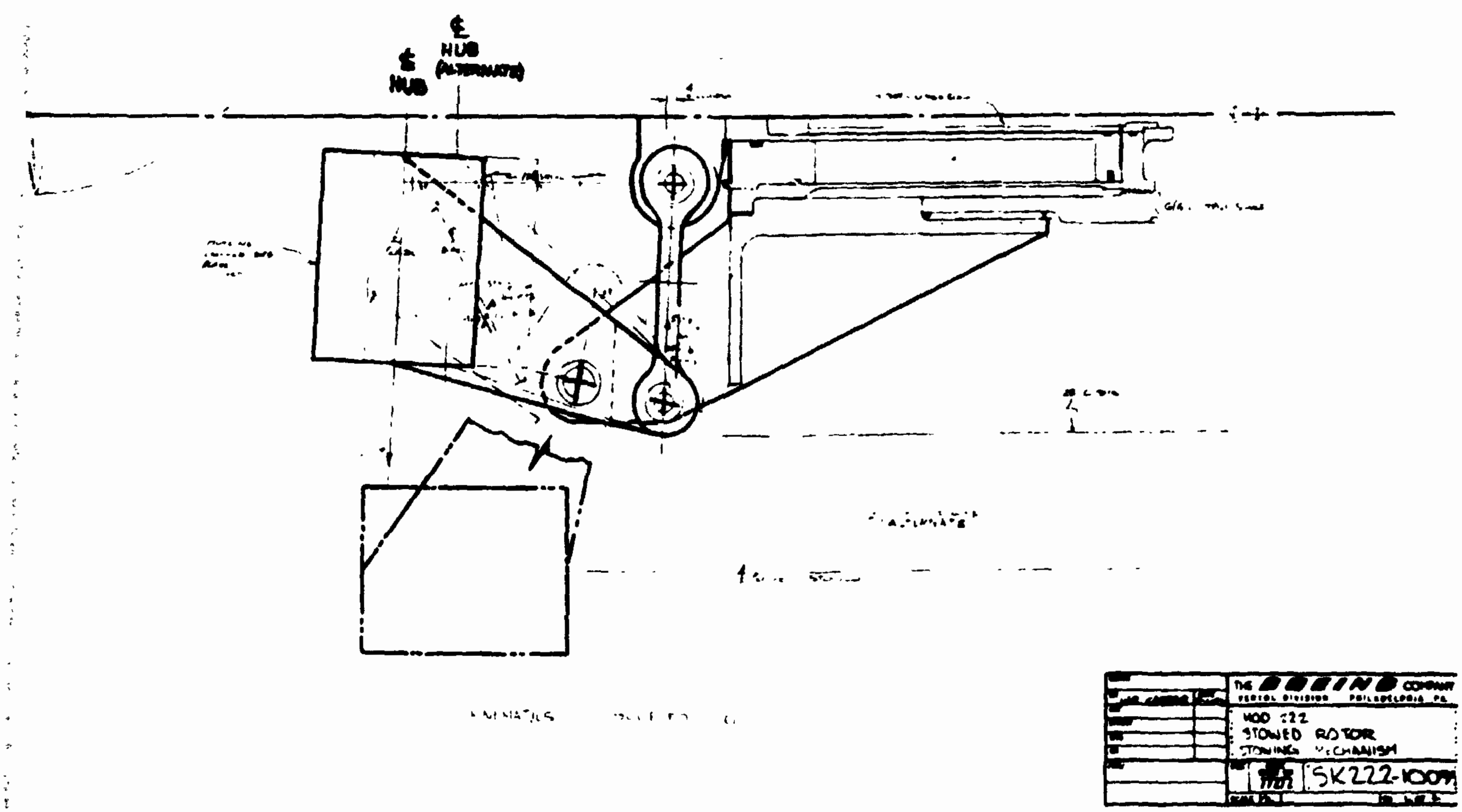

ADE FOLDING KINEMATICS

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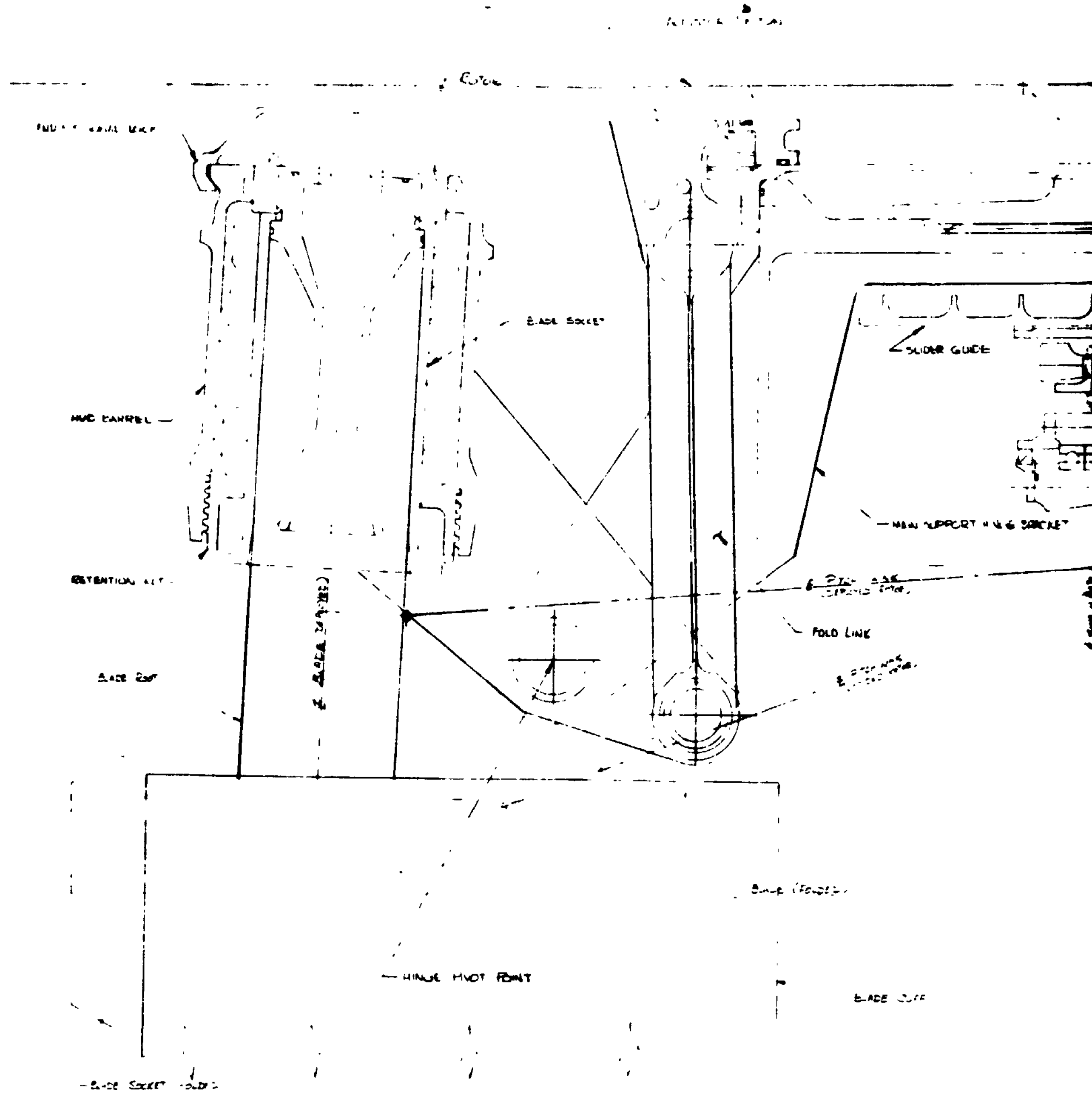
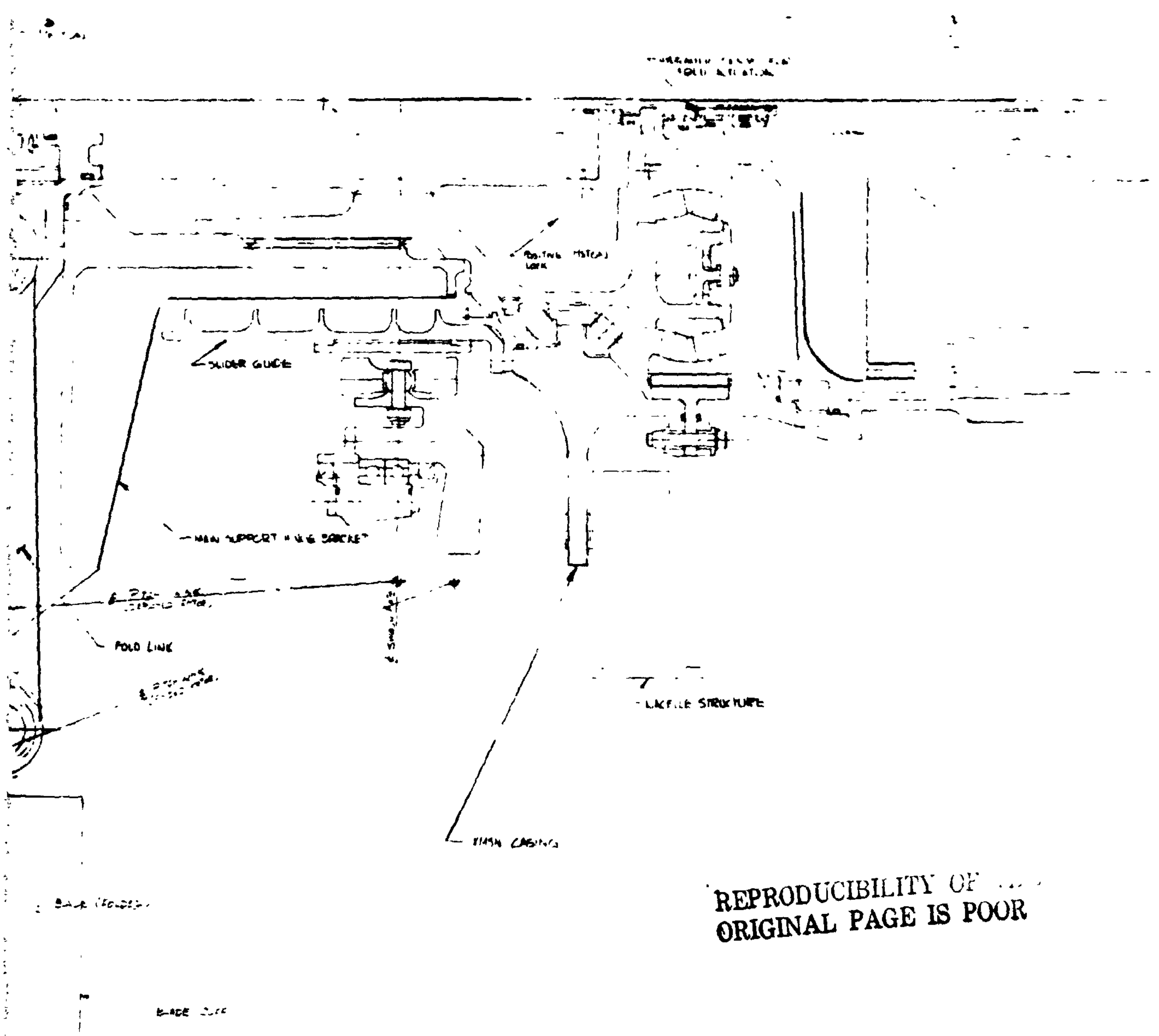
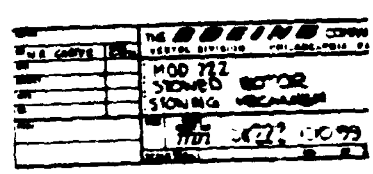


FIGURE 3-15: STOWED ROTOR HUB





.5: STOWED ROTOR HUB

blade lock that secures the blade to the fairing, and cuts hydraulic pressure to the blade fold system.

The unfolding sequence is the reverse of the above procedure.

As discussed previously in Section 3.2.1.4.1, the engine used in this aircraft is an advanced technology "convertible" engine. This engine will have the dual capability of a turbofan or of a turboshaft. These engines will be mounted beneath the wing at approximately mid-span with a cross shaft connecting the input bevel boxes for single engine rotor operation.

The wing size and geometry has been chosen for the most efficient and simple structural arrangement and nacelle attachment, consistent with the required relationship between nacelle tilt pivot and wing for correct CG location in hover and cruise flight.

Collective and cyclic pitch of the rotors, together with nacelle tilt, provide control in hover. In the cruise mode, control is by conventional airplane control surfaces; elevators, rudder, flaperons and spoilers. Leading edge "umbrella" flaps and large deflection trailing-edge flaps reduce download in hover. Operation of flaps, umbrellas and elevators as well as phasing out of the rotor controls is mechanically programmed with nacelle tilt to relieve pilot workload. A limited authority SAS includes feedback from angle-of-attack, yaw angle and dynamic pressure during rotor-operating conditions. This provides

increased static stability and reduces blade loads to increase fatigue margins. The aircraft can be safely flown with the feedback system inoperative.

The materials used extensively in this design will be of an advanced technology nature. Used will be materials like fiberglass/boron composite in the blades, graphite-boron and PRD-49 composites in skins and control surfaces, etc. Titanium alloys will be used where feasible. A 26 ft. diameter rotor system with the blades constructed of fiberglass/boron has already been constructed and wind tunnel tested for 150 hours under NASA contract NAS2-6505. Other advanced materials are being tested in Boeing Vertol Engineering Labs in a variety of configurations. An advanced technology transmission, of the type developed for the Heavy Lift Helicopter, will be used.

It is proposed to use conventional materials, i.e., steel and aluminum alloys for most dynamic components except blades.

The structural design of the aircraft will conform to the appropriate requirements laid down by the relevant military agencies. The structure will be optimized to meet the strength and stiffness criteria at minimum weight using finite element structural analysis computer programs.

The following installations and equipment have been assumed for the search and rescue mission: a minimum of five (5) litters and two (2) jump seats; a rescue winch and cable,

forest canopy penetrator; portable oxygen equipment; loud hailer; radome; two (2) searchlights; terrain radar antennae; glide slope receiver antennae; FM homing antennae, X-band antennae; TACAN/IFF transponder; IFF interragator (VHF); HF-SSB antennae; VOR/LOC antennae; radar warning sensor; low light level T-V; doppler antennae; marker beacon; sense antennae LF-ADF; ADF loop antennae and crash beacon.

3.3.1.2 Tilt Rotor SAR Aircraft

The Tilt Rotor SAR Aircraft is depicted in Figure 3-16. This aircraft is identical in configuration to that originally described in Reference 1 except that it is slightly smaller because of the differences in transmission and rotor sizing ground rules discussed in Section 3.2.1.3. Design Gross Weight is 15631 lb. Rotor diameter is now 25.8 ft.

The rotors are of the soft-in-plane, hingeless type identical in design to the one originally described in Reference 2. This design features advanced composite construction in the blades and an elastomeric blade retention system.

Advanced technology turboshaft engines are mounted in nacelles fixed to the wing tips. The engines do not tilt with the rotors. This arrangement simplifies engine installation design and minimizes drive system vulnerability.

Extensive use of advanced technology materials (graphite/boron and PRD-49/epoxy composites and titanium alloys) has been

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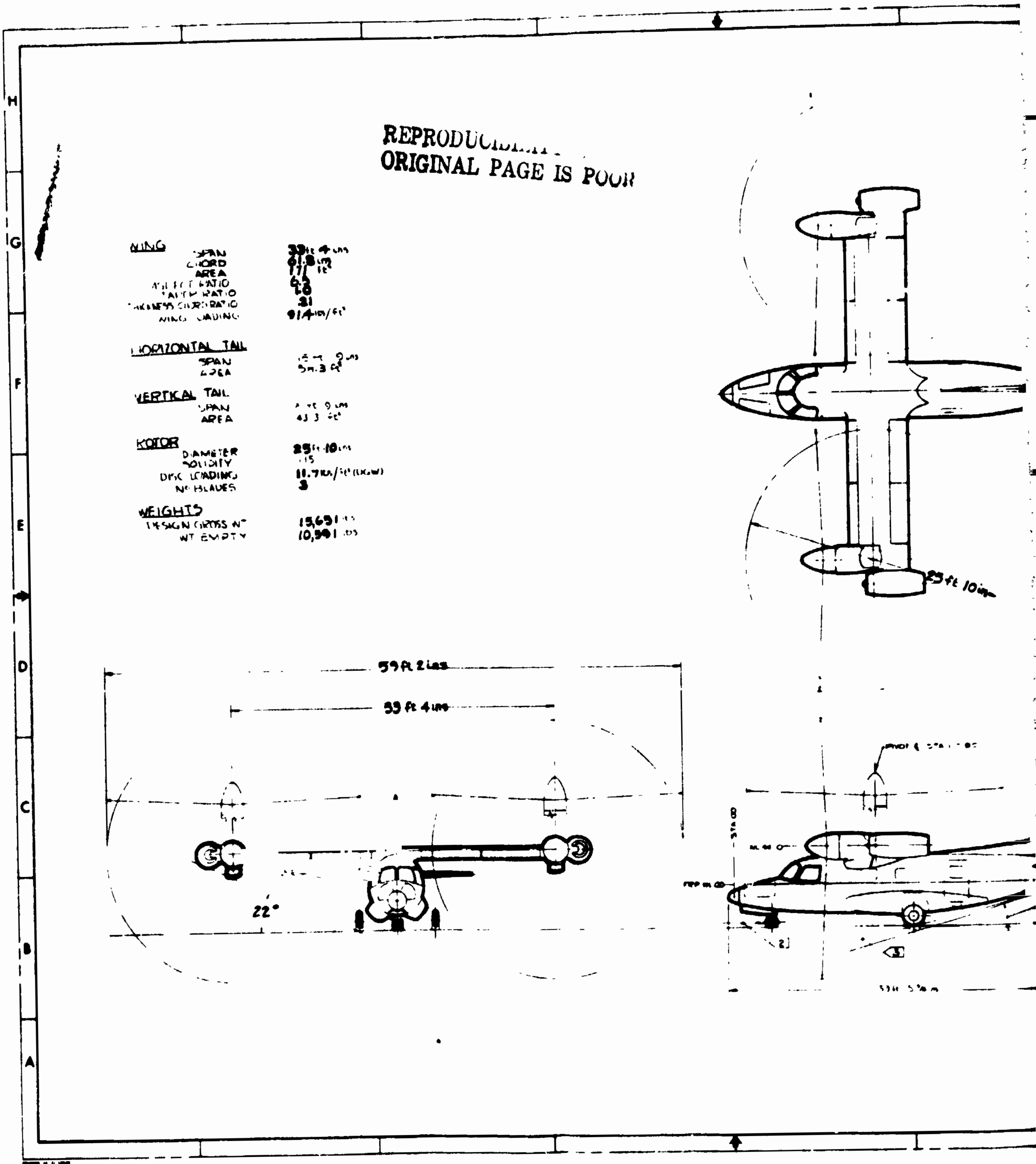
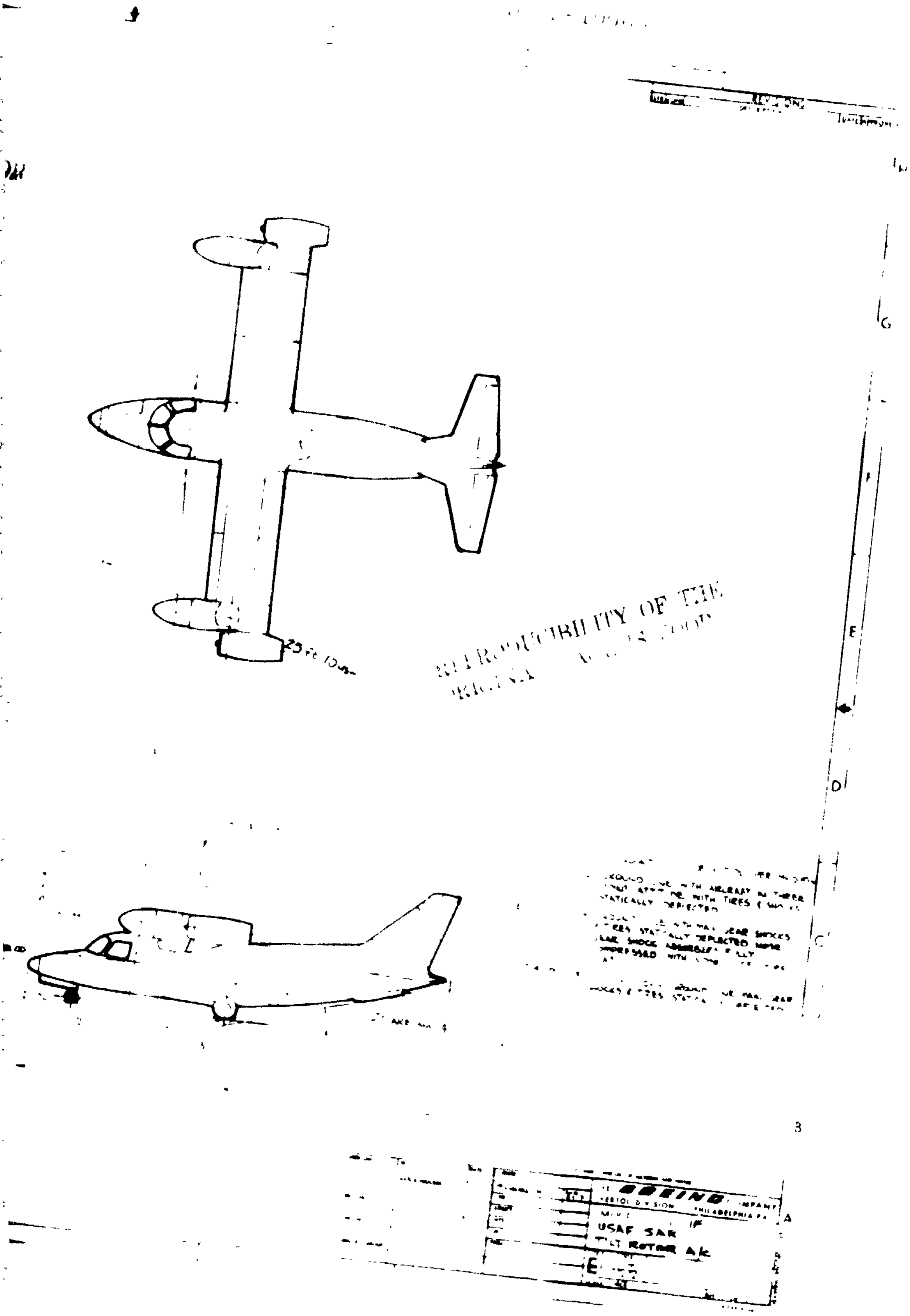


FIGURE 3-16: USAF SAR TILT ROTOR AIRCRAFT 3-VIEW

FOLDOUT FRAME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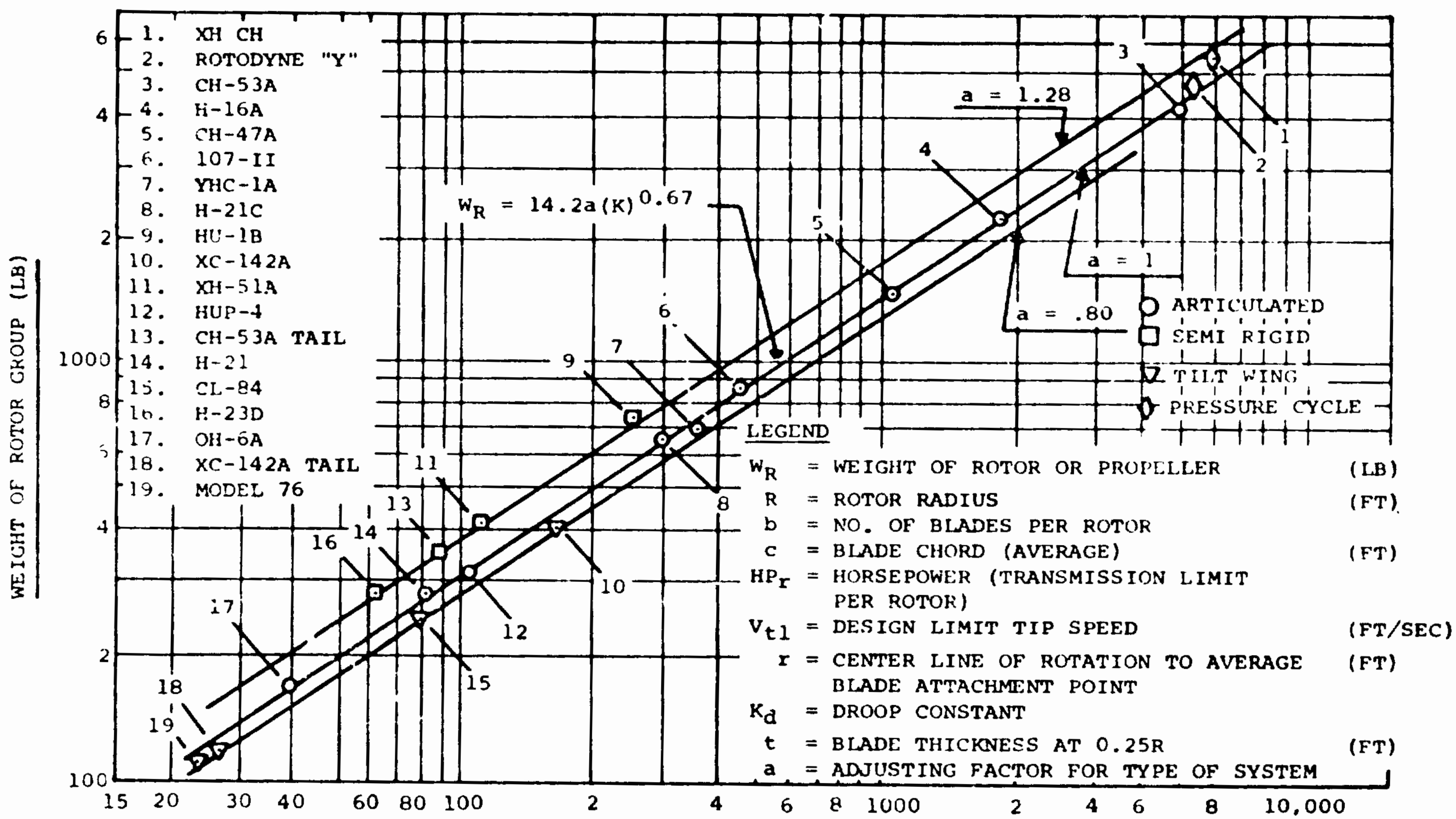
assumed in the design of the aircraft. Advanced technology transmissions are used. These considerations are the same as for the stowed rotor aircraft.

3.3.2 WEIGHT SUMMARY

Weight trade studies leading to the selection of the baseline configurations were accomplished using the VASCOMP computer program, described in Reference 14. The sizing program includes a weights subroutine which provides a consistent method for rapidly estimating the aircraft's operational weight empty. The program divides the empty weight into three groups;propulsion, structures and flight controls. Weight trends are programmed for each group and the program computes their respective weights. These are then combined with weight input values of fixed useful load, fixed equipment and payload to determine the weight of the fuel available for a given gross weight and payload. The weight input values were determined from specific mission requirements and/or specified equipment lists.

The weight trends were developed at Vertol from statistical and semi-analytical data for existing aircraft. They combine geometric, design and structural parameters into an accurate weight prediction tool. Examples of the weight trends for some of the major weight groups are presented in Figures 3-17 through 3-20.



$$K = \left[r\right]^{0.25} \left[\frac{HPr}{100}\right]^{0.5} \left[\frac{Vtl}{100}\right] \left[\frac{R.b.c}{10}\right] \Bigg| \left[\frac{R^{1.6}}{100K\ t}\right]$$

Figure 3-17: Rotor Group Weight Trend.

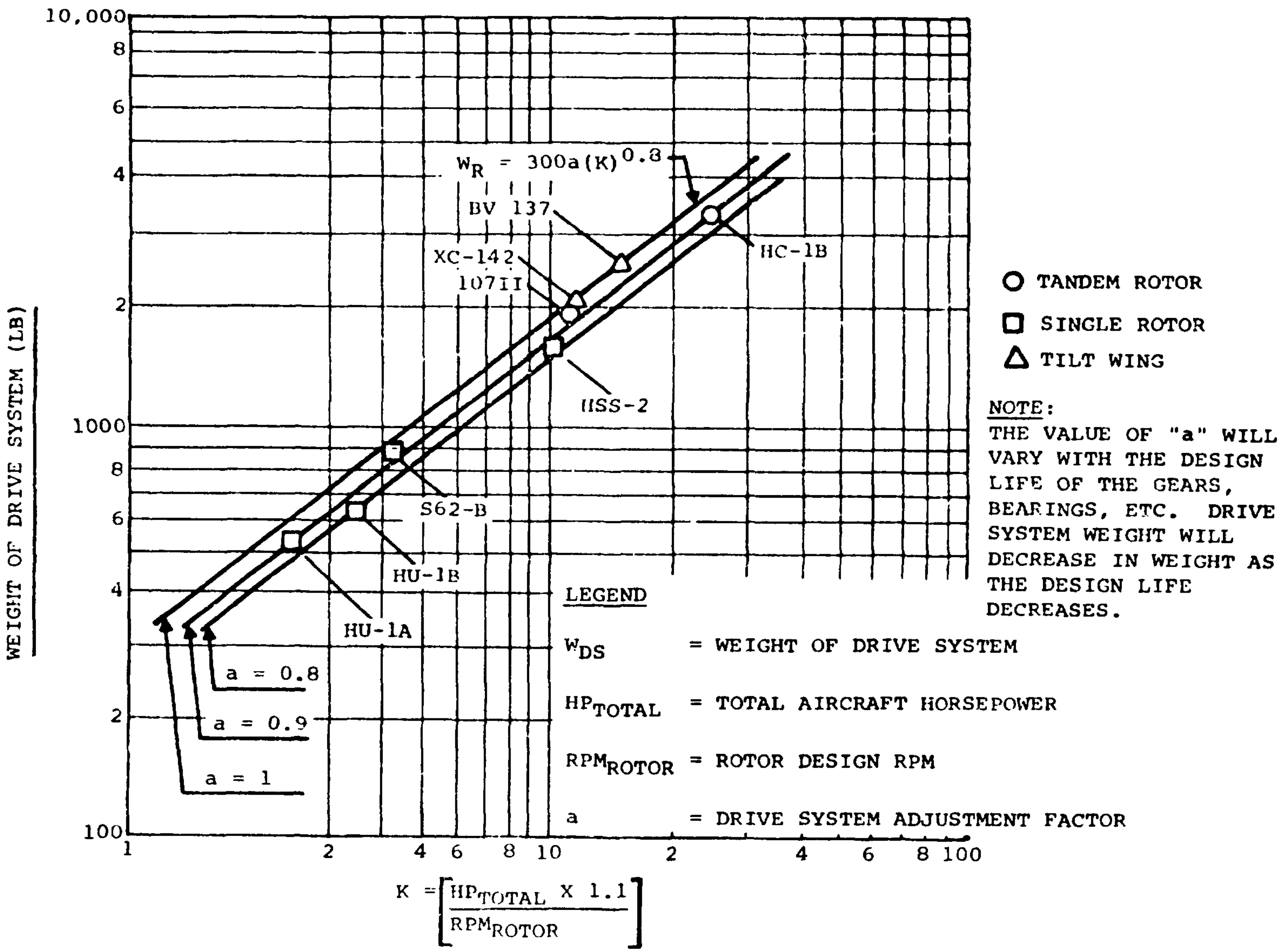
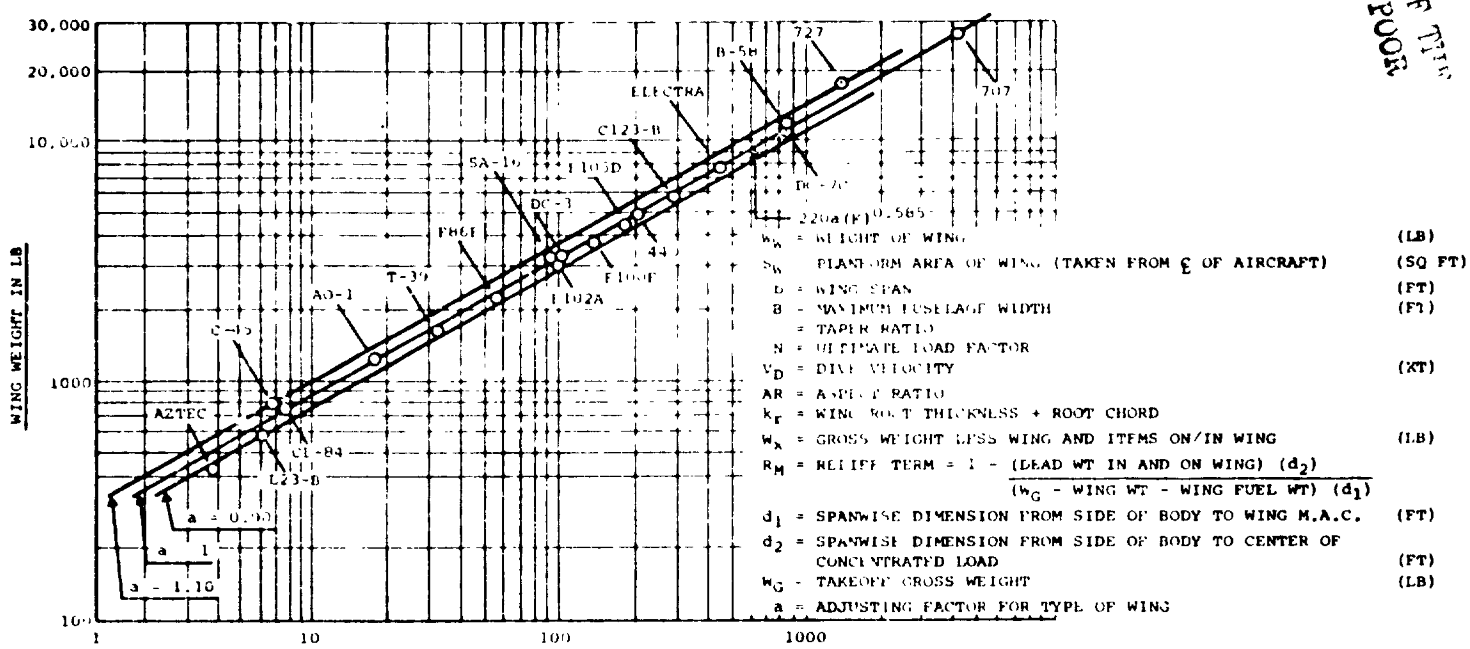
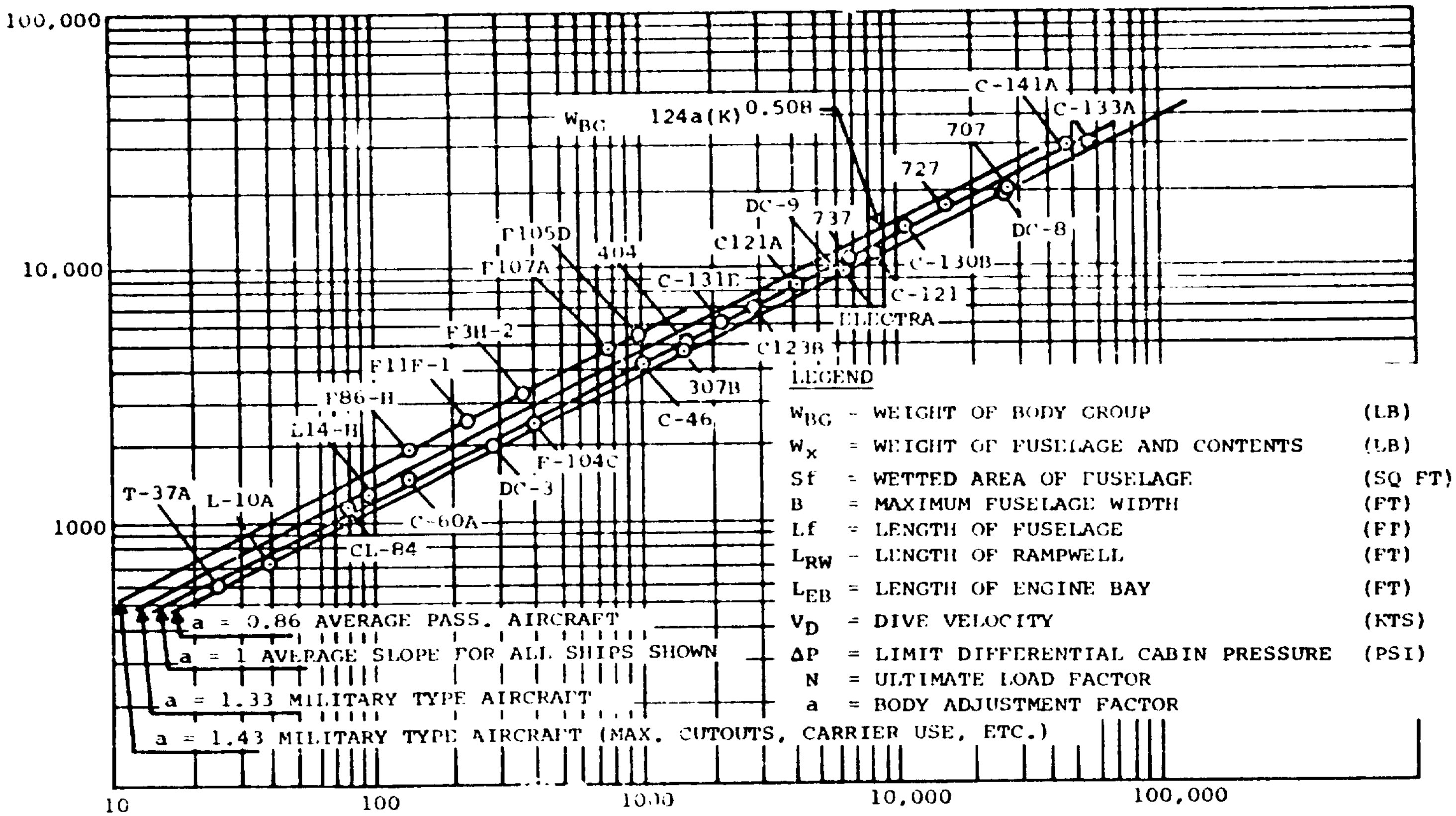


Figure 3-18: Drive System Weight Trend.



$$K = \left[\frac{R_M W_x}{10^4}\right]\left[\frac{S_W}{10^2}\right]\left[\log\frac{b}{B}\right]\left[\sqrt{\frac{1+\lambda}{2k_r}}\right]\left[\sqrt{N}\right]\left[\log_{10}V_D\right]\left[\log_{10}AR\right]$$

Figure 3-19: Wing Weight Trend.



$$K = \left[\frac{W_x}{10^4}\right]^{0.7} \left[\frac{St}{10^3}\right] B(Lf + L_{RW})^{0.5} \left[\log_{10} V_D\right] (\Delta P + 1) \quad (N)^{0.3}$$

Figure 3-20: **Body Group Weight Trend.**

The coefficients in the trend equations are primary inputs to the computer program. Selection of the constants depends on the type of aircraft being configured - tilt rotor, stowed rotor, etc. - material, and level of technology. Special design features such as folding rotor blades, tilting nacelles, etc. are studied individually and input as a variation of the constant or included as a direct weight input in the incremental group weight section of the VASCOMP weights input form.

A detailed description of the VASCOMP weights sub-routine appears in Reference 15.

Summary weight statements for the stowed rotor and tilt rotor design point aircraft are presented in Tables 3-1 and 3-2. The configuration weights utilize advanced composite materials in the structure (wing, fuselage,engine section) and rotor assembly. Advanced technology has been considered in the drive system (higher Hertz stress levels in the gearing for example) for both configurations. Weight savings of between 15 to 20 percent of the individual groups are realized through the use of the advanced materials and advanced technology.

3.3.3 PERFORMANCE

The performance characteristics of the stowed rotor and tilt rotor aircraft are presented in the following sections. The data presented include:

a. Flight Envelope

TABLE 3-1 SUMMARY WEIGHT STATEMENT
USAF-SAR. (STOWED ROTOR)

ROTOR DIA./σ →	30.3'/.081	
H.P. TOTAL →	4909	
WING AREA →	175 FT^2	
ROTOR GROUP	1227	
WING GROUP	747	
TAIL GROUP	200	
BODY GROUP	1180	
BASIC		
SECONDARY		
SECOND.-DOORS, ETC.		
ALIGHTING GEAR	620	
FLIGHT CONTROLS	1230	
ENGINE SECTION	182	
PROPULSION GROUP	(3737)	
ENGINES(S)	1237	INCLUDES ENG, FANS, SHROUDS, DRIVE SYS.
AIR INDUCTION		
EXHAUST SYSTEM		
COOLING SYSTEM	200	
LUBRICATING SYSTEM		
FUEL SYSTEM	700	
ENGINE CONTROLS		
STARTING SYSTEM		
PROPELLER INST.		
*DRIVE SYSTEM	1200	
TIP POD	400	
AUX. POWER PLANT	-	
INSTR. AND NAV.	135	
HYDR. AND PNEU.	130	
ELECTRICAL GROUP	800	
ELECTRONICS GROUP	1500	
ARMAMENT GROUP	175	
FURN. & EQUIP. GROUP	350	FIXED EQUIP. (3300#) WAS ESTIMATED
PERSON. ACCOM.		3300 FROM DISCUSSIONS WITH MAC RESCUE
MISC. EQUIPMENT		EQUIP. PERSONNEL AT SCOTT AFB
FURNISHINGS		
EMERG. EQUIPMENT		
AIR COND. & DE-ICING	100	
PHOTOGRAPHIC		
AUXILIARY GEAR	110	• Forest Penetrator
		• Folding Litters
		• Rescue Litter
MFG. VARIATION		• Troop Seat Instl.
WEIGHT EMPTY	12423	• Life Raft
FIXED USEFUL LOAD		• Rescue Sling
CREW (4)	860	• Flares & Gun
TRAPPED LIQUIDS	40	• Water + Container
ENGINE OIL		• Misc
MISSION EQUIP	150	
FUEL	5452	
CARGO		
PASSENGERS/TROOPS		
GUNS & AMMO	145	(5.56 MM Gun == 35#, 3000 Rds Ammo -- 110#)
GROSS WEIGHT	19070	

TABLE 3-2 SUMMARY WEIGHT STATEMENT
USAF-SAR. (TILT ROTOR)

ROTORDIA./σ	25.8'/.091				
H.P. TOTAL	3693				
WING AREA	171 FT^2				
ROTOR GROUP	905				
WING GROUP	702				
TAIL GROUP	200				
BODY GROUP	1160				
BASIC					
SECONDARY					
SECOND.-DOORS, ETC.					
ALIGHTING GEAR	595				
FLIGHT CONTROLS	1214				
ENGINE SECTION	425				
PROPULSION GROUP	(2089)				
ENGINES(S)	587				
AIR INDUCTION					
EXHAUST SYSTEM					
COOLING SYSTEM	200				
LUBRICATING SYSTEM					
FUEL SYSTEM	385				
ENGINE CONTROLS					
STARTING SYSTEM					
PROPELLER INST.					
*DRIVE SYSTEM	917				
AUX. POWER PLANT	-				
INSTR. AND NAV.	135				
HYDR. AND PNEU.	130				
ELECTRICAL GROUP	800				
ELECTRONICS GROUP	1500		FIXED EQUIP. (3300#) WAS ESTIMATED		
ARMAMENT GROUP	175		FROM DISCUSSIONS WITH MAC.		
FURN. & EQUIP. GROUP	350	3300	PERSONNEL AT SCOTT AFB.		
PERSON. ACCOM.					
MISC. EQUIPMENT					
FURNISHINGS					
EMERG. EQUIPMENT					
AIR COND. & DE-ICING	100				
PHOTOGRAPHIC	-				
AUXILIARY GEAR	110		• Forest Penetrator		
			• Folding Litters		
			• Rescue Litter		
MFG. VARIATION			• Troop Seat Instl.		
WEIGHT EMPTY	10590		• Life Raft		
FIXED USEFUL LOAD			• Rescue Sling		
CREW (4)	860		• Flares & Gun		
TRAPPED LIQUIDS	40		• Water + Container		
ENGINE OIL			• Misc		
Mission Equip.	150				
FUEL	3846				
CARGO					
PASSENGERS/TROOPS					
Guns & Ammo	145	(5.56MM Gun--35#, 3000 rds, Ammo -- 110#)			
GROSS WEIGHT	15631				

• INCLUDES ——— LB. XXX. TL

REV.

b. Hover Ceiling

c. Payload-Radius Capability

Payload-radius performance is based on an alternate "HI-LO-LO-HI" SAR mission profile. The mission, shown in Figure 3-21, begins as the design mission does with a climb to 20,000 ft/STD and cruise outbound at NRP. At the 60% radius point, however, descent is then made (with no range credit) to 3000 ft/95°F and the cruise is continued at low altitude. Two speed conditions, Normal-power speed and 99%-best-range speed, were considered for this low-level leg. Midpoint activities are the same as the design mission. The HI-LO profile is then reversed for the return leg.

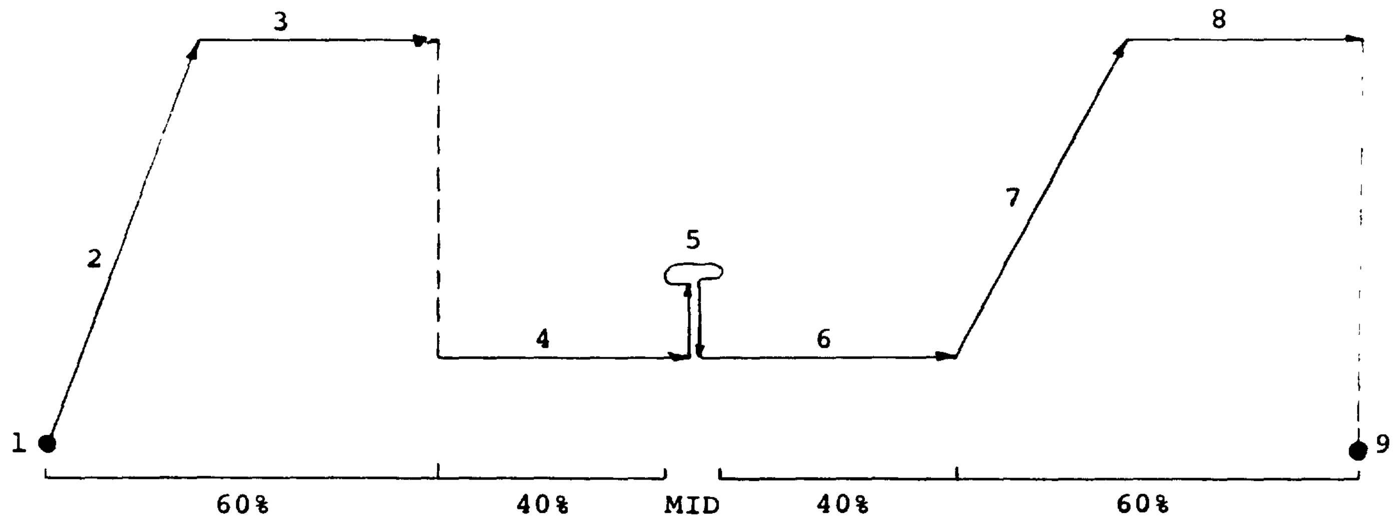
3.3.3.1 Stowed Rotor Aircraft

3.3.3.1.1 Flight Envelope

The estimated flight envelope for the stowed rotor aircraft is presented in Figure 3-22. The data are presented for 19070 lb gross weight. The aircraft is in the rotors-folded or fan-propelled mode.

3.3.3.1.2 Hover Ceiling

Figure 3-23 shows the out-of-ground-effect hover capability for the stowed rotor aircraft. The curves are based on a 10% thrust margin for hover (T/W=1.1) which is sufficient to provide 500 fpm vertical rate of climb capability. The transmission



1. WARM UP, TAXI AND TAKEOFF: 3 MIN. @ NORMAL RATED POWER, SEA LEVEL, 95°F
2. CLIMB TO 20,000 FT @ MILITARY POWER AND SPEED FOR MAXIMUM RATE OF CLIMB
3. CRUISE OUTBOUND @ NORMAL RATED POWER
4. CRUISE @ 3000 FT, @ NORMAL RATED POWER, 95°F
5. HOVER 1/2 HR., EFFECT RESCUE OF 3 PEOPLE (600 LBS) @ 5000'/95°F
6. CRUISE @ 3000 FT @ NORMAL RATED POWER, 95°F
7. CLIMB TO 20,000 FT @ MILITARY POWER AND SPEED FOR MAXIMUM RATE OF CLIMB
8. CRUISE INBOUND @ NORMAL RATED POWER
9. LAND WITH 10% (INITIAL) FUEL RESERVE

NOTES:

1. MISSION FLOWN @ STANDARD ATMOSPHERE CONDITIONS UNLESS OTHERWISE NOTED.
2. SFC INCREASED 5% PER MIL-C-5011A.

FIGURE 3-21: USAF SAR HI-LO-LO-HI MISSION PROFILE

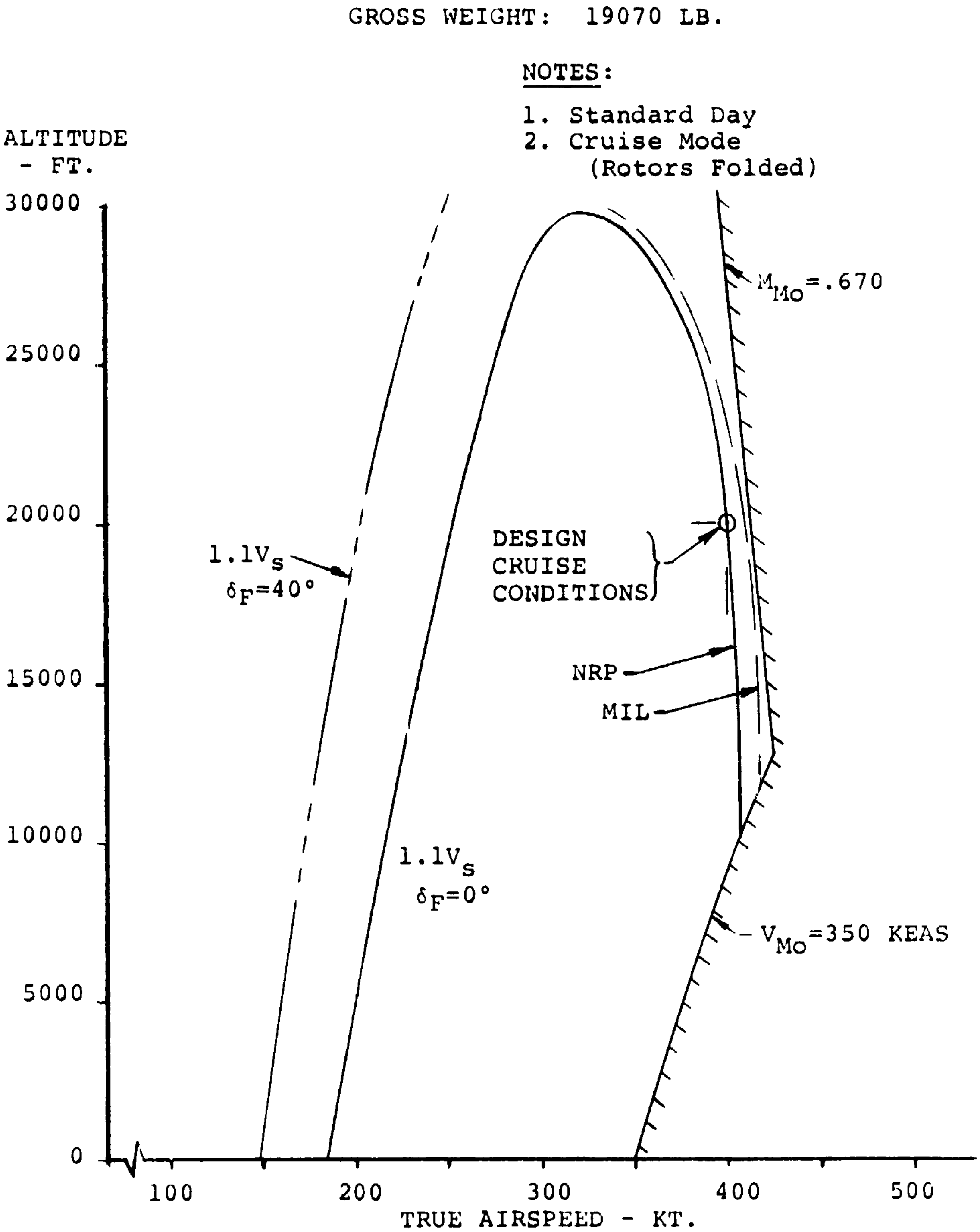


FIGURE 3-22: STOWED ROTOR FLIGHT ENVELOPE

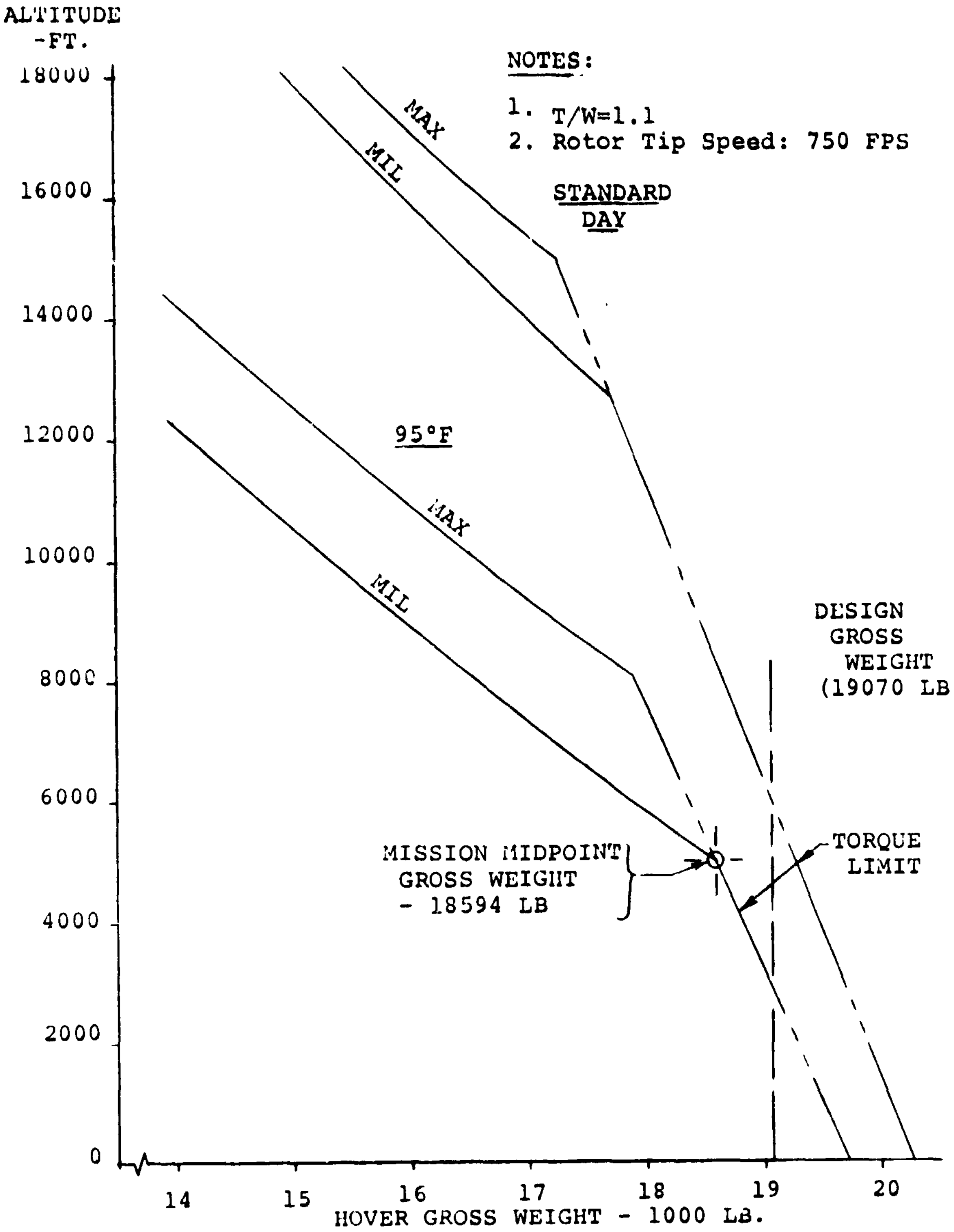


FIGURE 3-23: STOWED ROTOR OUT-OF-GROUND-EFFECT HOVER CAPABILITY

limit is at the military power torque level at 5000 ft/95°F (Section 3.2.1.3).

3.3.3.1.3 Payload-Radius

Payload-radius capability based on the HI-LO-LO-HI SAR mission (Figure 3-21) is shown in Figure 3-24. Cruising at low altitude over a portion of the radius has an adverse effect on payload-radius performance. For the NRP cruise case the internal fuel limit is reached at 400 NM. At this distance the aircraft has a 2300 lb payload capability which provides a 900 lb payload margin over the basic requirement. The aircraft could meet the 500 NM radius requirement with external fuel or air-to-air refueling.

3.3.3.2 Tilt Rotor Aircraft

3.3.3.2.1 Flight Envelope

The flight envelope for the tilt rotor aircraft is shown in Figure 3-25 for 15631 lb GW. The aircraft is configured for the cruise mode: nacelles down and a rotor tip speed of 525 fps (70% max.).

3.3.3.2.2 Hover Ceiling

The out-of-ground-effect hover performance for the aircraft is shown in Figure 3-26. Rotor tip speed is 750 fps and a 10% thrust margin (T/W=1.1) has been assumed. The transmission torque limit is fixed by the 20,000 ft military power cruise

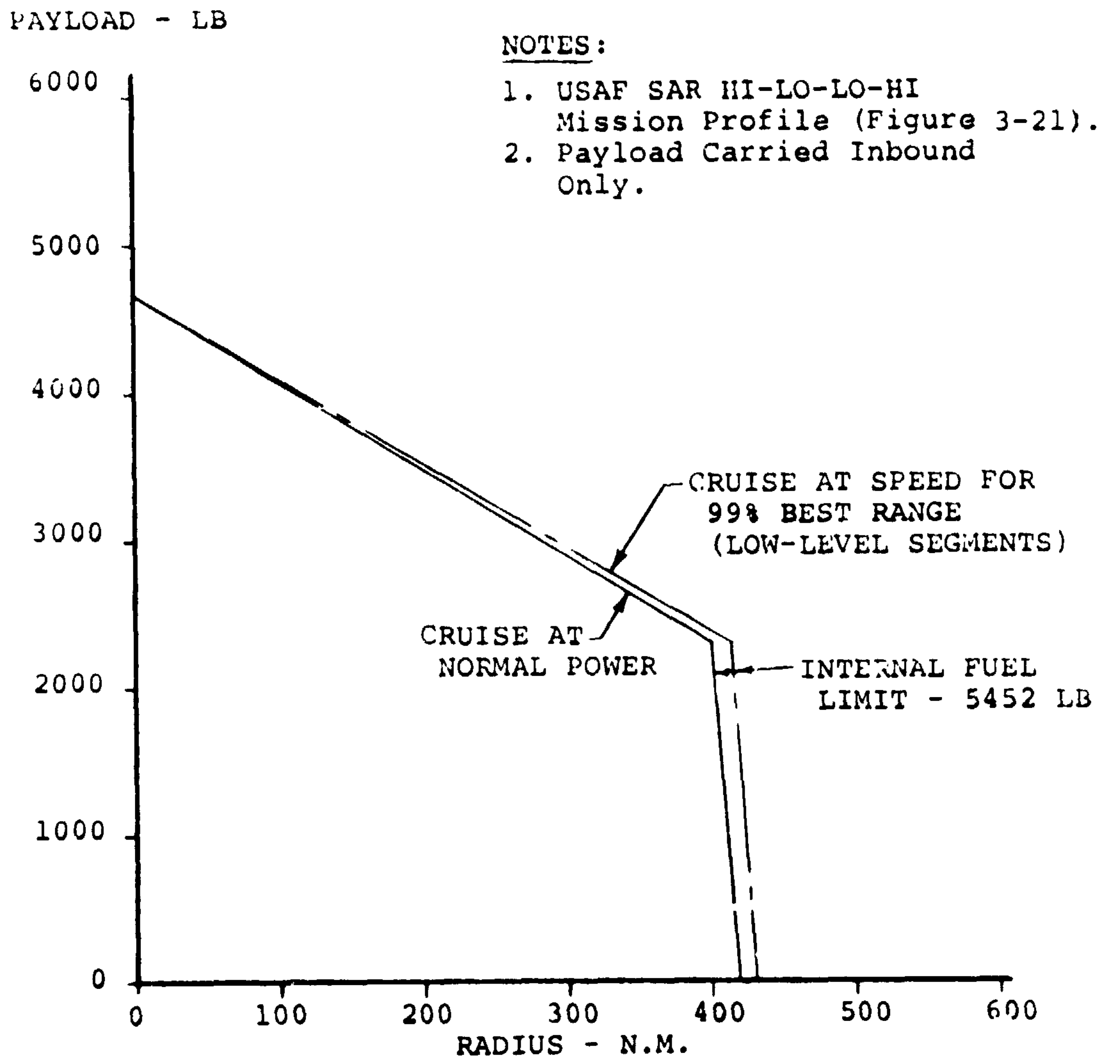


FIGURE 3-24: STOWED ROTOR PAYLOAD - RADIUS CAPABILITY HI-LO-LO-HI SAR MISSION PROFILE

condition (Section 3.2.1.3). Consequently the tilt rotor can hover at higher gross weights relative to the midpoint gross weight than the stowed rotor.

3.3.3.2.3 Payload-Radius

Figure 3-27 shows the mid-point payload-radius performance of the tilt rotor based on the HI-LO-LO-HI mission. Because this aircraft uses less mission fuel than the stowed rotor, it has a flatter payload-radius curve.

GROSS WEIGHT: 15631 LB

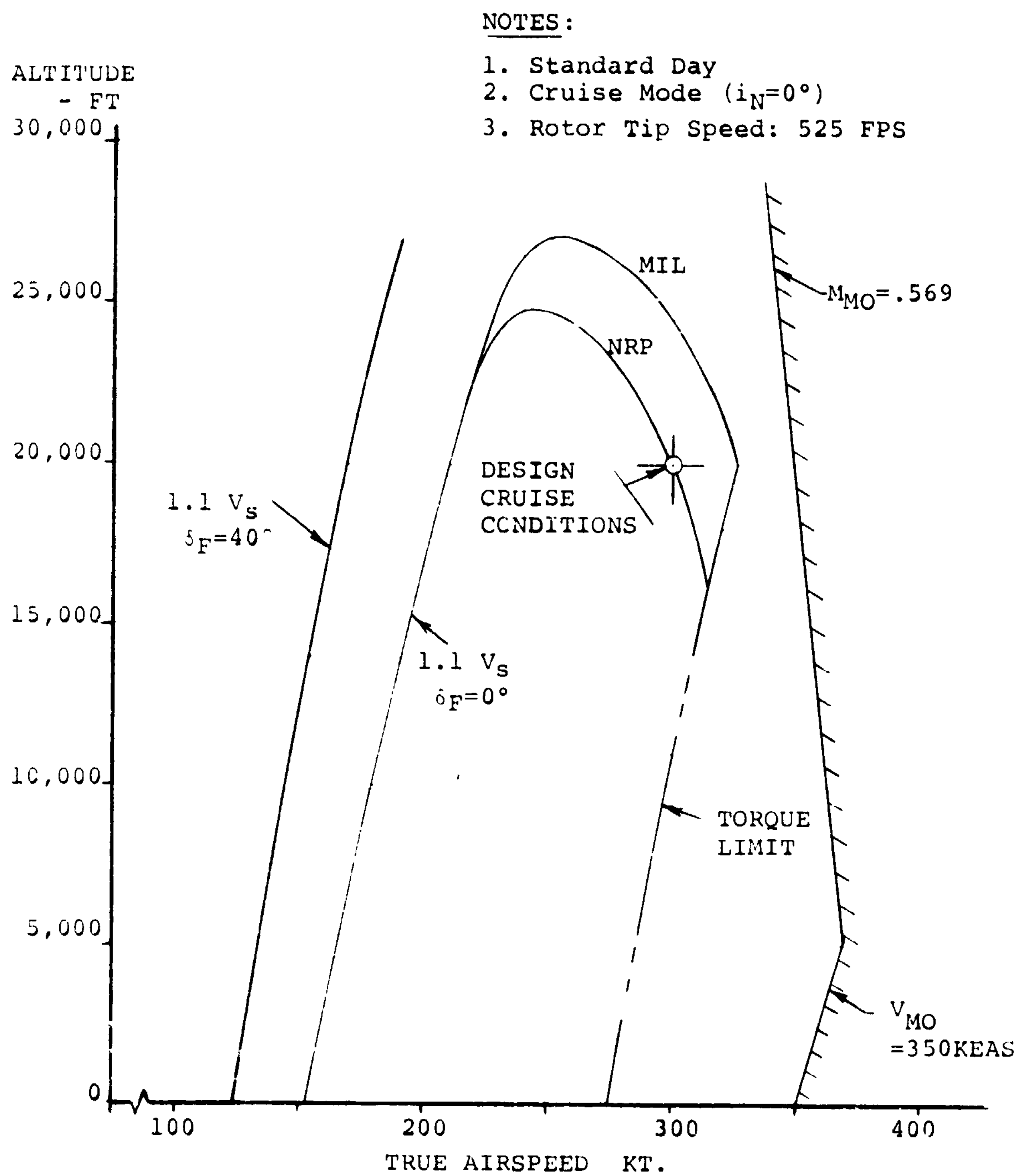


FIGURE 3-25: TILT ROTOR FLIGHT ENVELOPE

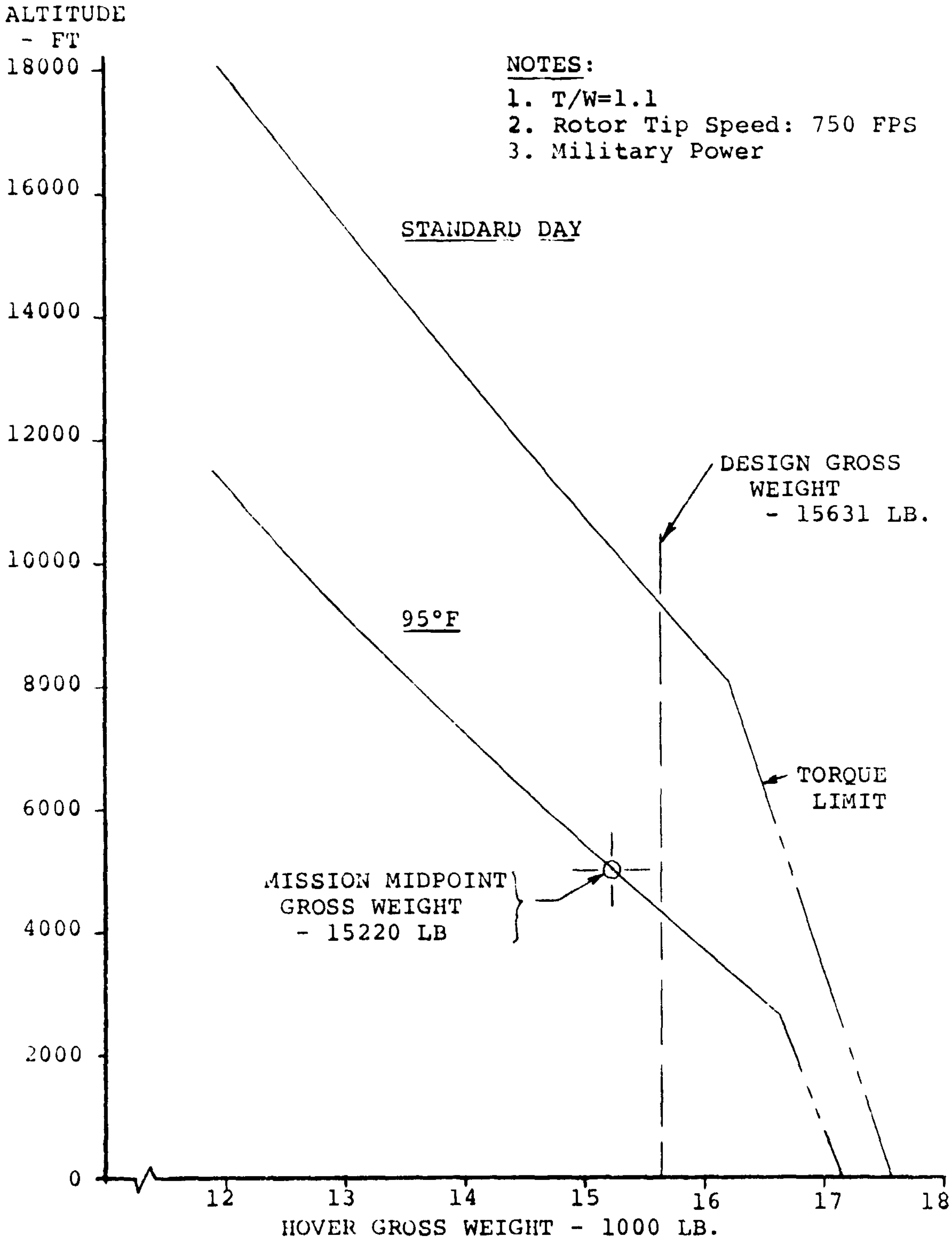


FIGURE 3-26: TILT ROTOR OUT-OF-GROUND EFFECT HOVER CAPABILITY

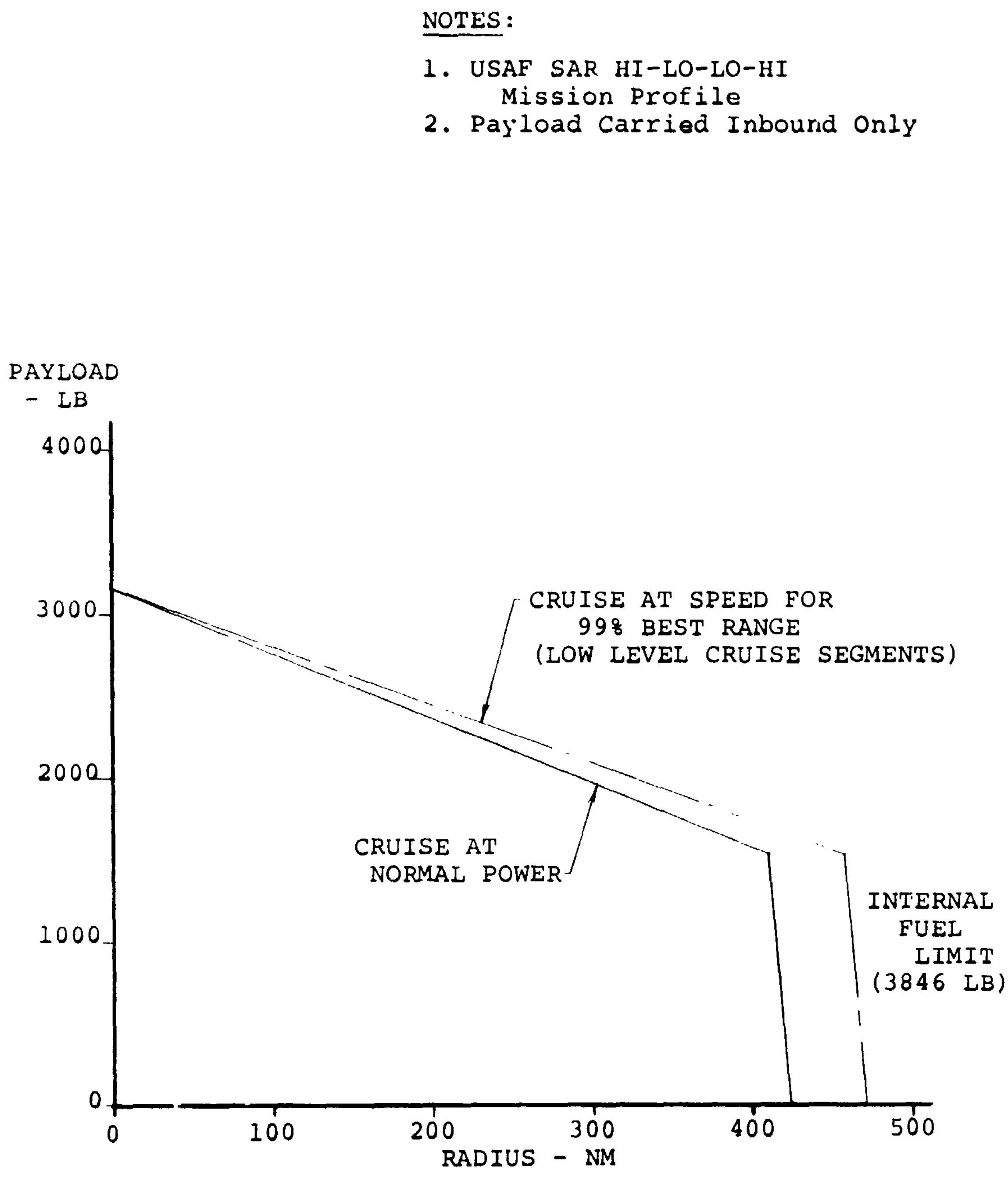


FIGURE 3-27: TILT ROTOR PAYLOAD-RADIUS CAPABILITY - SAR HI-LO-LO-HI MISSION PROFILE

4.0 PRELIMINARY DESIGN OF STOWED ROTOR RESEARCH AIRCRAFT

4.1 DESIGN CONSIDERATIONS

Three possible approaches which would provide the USAF with a rescue demonstrator were considered:

(a) Build two complete stowed rotor rescue aircraft for USAF in addition to the two tilt rotor research aircraft planned for NASA.

(b) Modify the two NASA tilt rotor aircraft, after completion of the NASA tests, to a stowed rotor configuration for USAF evaluation.

(c) Modify one or both of the NASA tilt rotor aircraft, after completion of the NASA tests, to provide a tilt rotor rescue aircraft for USAF evaluation.

The first approach, building two complete stowed rotor aircraft for the USAF has the advantage of providing USAF stowed rotor demonstrators essentially independent of the NASA program, and would provide the earliest USAF aircraft, since there is no need to wait for completion of NASA tests. However, it is also the most expensive approach. The only cost benefit derived from the NASA program would be in the design area. Since it has been made clear that the USAF could not fund a separate demonstrator program, this approach was not pursued further.

The second approach, modifying the NASA aircraft to a stowed rotor configuration after completion of the NASA tests,delays the USAF program, but results in a substantial cost saving. The NASA fuselage and landing gear can be used with no modification other than providing a hoist installation and some local structural reinforcement at the aft end. The wing can be used with modifications. The rotor control system can be used almost unchanged. This approach was selected for the program definition of Section 4 of this report.

The third approach, modifying the NASA aircraft to a tilt rotor rescue configuration after completion of the NASA tests, does not, of course, provide the USAF with a stowed rotor aircraft. The basic capabilities and characteristics of the tilt rotor configuration will be established during the NASA program, which will include not only performance and flying qualities, but also environmental effects such as downwash. A good general evaluation of the suitability of the tilt rotor configuration for the rescue mission could be obtained from the NASA data with no additional effort. This could be supplemented by providing a rescue hatch and winch, permitting both dummy and live pick-ups, and by installing a turret for weapons firing tests. The items, however, are relatively short lead time, and would not need to be initiated before first flight of the NASA aircraft. This approach was therefore not pursued further at this time.

4.1.1 ENGINE SELECTION AND PLACEMENT

A stowed rotor aircraft designed for operational use would use the convertible cruise fan concept for propulsion (see, for example, Reference 5). In this concept a core engine is used to drive a variable-pitch fan (such as the Hamilton-Standard "Q-Fan") or the rotors depending on the flight mode. Since fans of this type are not yet available on the production basis (which was one of the ground rules for engine selection), it was necessary to use separate engines for cruise and hover for the demonstrator aircraft. The T-53 engines were retained to power the rotors. These were moved to the underwing location to permit the rotor blades to be folded flat along the rotor nacelles.

No specific performance conditions were specified as criteria for cruise engine selection. It was considered necessary that the aircraft not be thrust-limited in cruise and desirable that it be able to approach the drag-divergence Mach number at high altitudes.

Two candidate engines were found in the desired thrust class (F_N=3000 lb, SL/STD, static). These were the Garrett/Airesearch TFE731-2 rated at 3500 lb thrust and the AVCO/Lycoming LAF-301B rated at 2900 lb. Both engines gave adequate performance but the Garrett engine enjoys the advantage of being in an advanced state of development. Since it also gave better performance, the Garrett engine was selected for the cruise propulsion role.

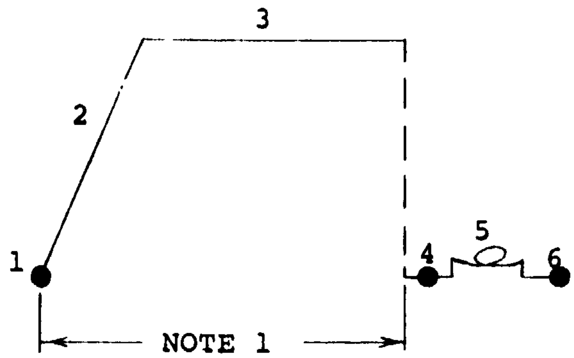
Several locations were considered for placement of the cruise engines. The aft fuselage location was rejected immediately because it would have created severe balance problems and because it would have required extensive modifications to the fuselage. The underwing location, on the other hand, caused no balance problem and would be simplest to incorporate into the design of the aircraft. Consequently, the cruise engines were placed under the wing, far enough outboard to minimize fuselage-nacelle interference, but close to the wing to provide a rigid mount and not influence the turnover angle.

4.1.2 MISSION PROFILE

A simulated search and rescue mission was used as a basis for computing the design gross and fuel weights for the aircraft. The mission profile used is shown in Figure 4-1. This mission profile is designed to simulate the use of the aircraft to investigate air terminal approach and departure operational procedures with the stowed/tilt rotor aircraft.

4.1.3 AIRCRAFT DRAG

The parasite drag breakdown for the aircraft is shown in Table 4-1. The drag area increments for the fuselage, wing, empennage, and landing gear pods were taken from the March 1972 drag breakdown for the M222 Tilt Rotor Research aircraft. New estimates were made for the tip pod and rotor engine nacelles. The cruise engine nacelle drag increment was



1. Warm-up, taxi, and takeoff: 2 min @ maximum power
2. Climb to 10,000 ft at military power and speed for max R/C
3. Cruise out at speed for 99% best range at 10,000 ft.
4. Takeoff, hover, or land at L/W=1.0 for 28 min.
5. Loiter for 5 min.
6. Takeoff, hover, or land at L/W=1.0 for 5 min.
7. 10% (initial) fuel reserve at end of mission.

NOTES:

1. Climb/cruise distance determined by one-hour total flight time duration.
2. All operations at sea level/std conditions unless otherwise noted.
3. Sfc increased 5% per MIL-L-5011A

Figure 4-1. Research Aircraft Mission Profile

TABLE 4-1

MINIMUM PARASITE DRAG BREAKDOWN 300 KTS, 10,000' STD., M=.470

Configuration: Stowed Rotor Research Aircraft 26' Rotor

R_e/ft. Drawing No. SK 24813

COMPONENT	WETTED AREA	C_f	INCREMENT %	INCREMENT f_e	f_e (ft^2)
FUSELAGE	401	.00205		.8221	
3-Dimensional Effects			13.1	.1074	
Excrescences			8.2	.0674	
Canopy			9.1	.0748	
Cross Section			1.0	.0082	
Roughness			3.0	.0247	1.1046
WING	360	.00267		.9607	
3-D Effects			67.	.6440	
Excrescences			7.	.0669	
Gaps Flaps, Slats Ailerons, Spoilers			34.	.3244	
Body Interference				.5921	2.5212
HORIZONTAL TAIL	114	.0289		.3295	
3-D Effects				.1051	
Excrescences & Gaps				.0481	
Interference				.0082	.4909
VERTICAL TAIL	87.6	.00277		.2427	
3-D Effects				.0619	
Excrescences & Gaps				.0339	
Interference				.00316	.3417
NACELLES, ROTOR	220	.00229		.504	
3-D Effects			8.4	.042	
Excrescences			23.0	.116	
Interference			15.6	.079	
Blades (Folded)			30.5	.154	.895
NACELLES, ROTOR ENGINE	84	.00250		.2100	
Discrete Roughness				.0064	
Excrescences				.0976	
Interference				.0618	
Inlets				.8250	
Base and Boattail				.2064	1.4072
NACELLES, CRUISE ENGINE	120				1.0
LANDING GEAR POD	92	.00244		.2245	
3-D Effects				.0351	
Excrescences				.0733	
Interference				.0666	.3995
TOTALS	1179				8.160

obtained from the estimate made for the parametric study (Section 3.2.1.5). It was assumed that the rotor engines are shut down in cruise and that there is no flow through the nacelles. Actually, there will be some leakage through the engine which would reduce the inlet and base drag increments but the no-flow condition was retained for conservatism.

4.2 AIRCRAFT DESCRIPTION

4.2.1 GENERAL

The Stowed Rotor Research Aircraft (Figure 4-2) is a conversion of the Boeing Vertol Model 222 Tilt Rotor Research Aircraft. The stowed rotor version will use essentially the same 26 foot diameter soft-in-plane rotor except that a new hub will be made to allow blade folding. The basic configuration of the tilt rotor will be retained although there will be differences in detail design resulting from the addition of the cruise engines, relocation of the rotor-drive engines, and incorporation of blade folding.

The aircraft has four engines: two to drive the rotors and two for cruise propulsion with rotors folded. The rotors are driven by modified Lycoming T53-L-13B turboshaft engines rated at 1550 SHP. These are mounted beneath the wings and drive the rotors through a cross-shafted drive system. The cruise engines are Garrett/Airesearch TFE731-2 turbofans rated at 3500 lb static thrust. These engines are also mounted beneath the wing inboard of the rotor-drive engines.

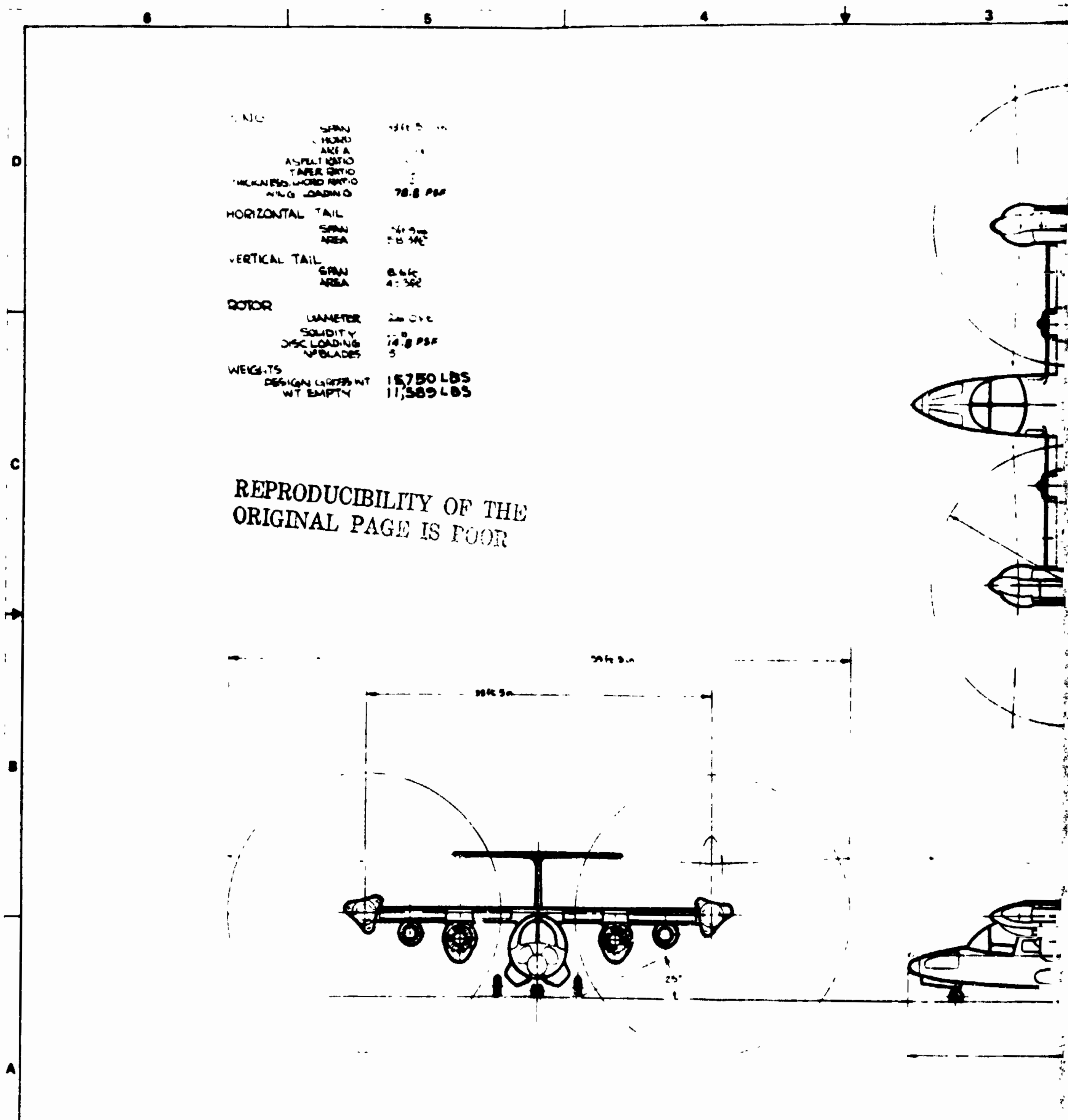
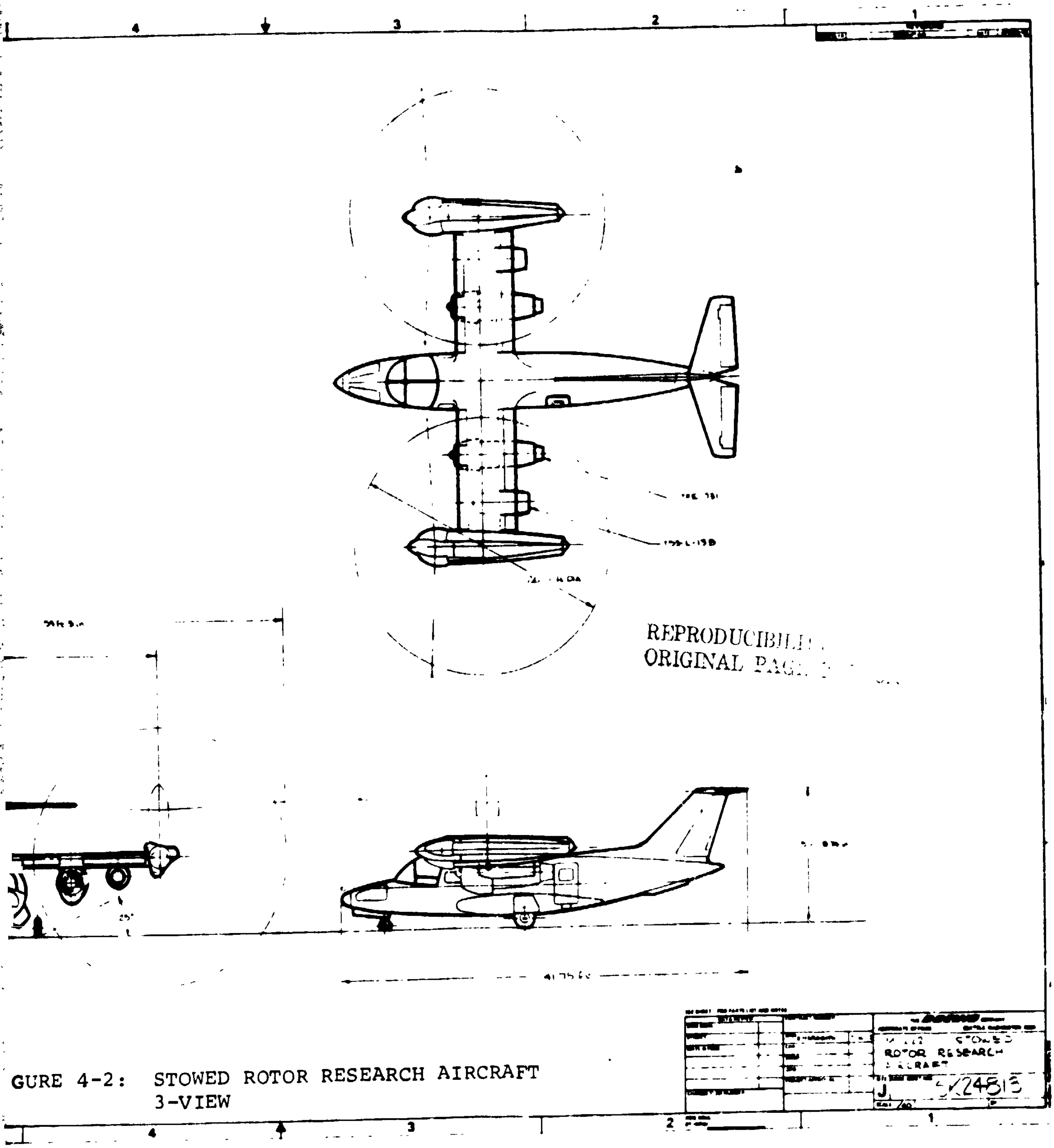


FIGURE 4-2: STOWED ROTOR RESEARCH AI[illegible]
3-VIEW



GURE 4-2: STOWED ROTOR RESEARCH AIRCRAFT
3-VIEW

In flight the rotors tilt from the hover position (rotor disc horizontal) to the cruise position (rotor disc vertical). The turbofan engines are then brought up to cruise thrust and the rotor engines are shut down and declutched from the rotors. The rotor blades are then feathered and the rotor slowed to a stop. The blades are then folded and stowed as described in Section 3.3.1. This procedure is reversible at any point to enable the aircraft to reconvert and retransition to the hover configuration.

The control systems of the tilt rotor research aircraft will be utilized in the stowed rotor aircraft. Collective and cyclic pitch of the rotors, together with nacelle tilt, provide control power in hover. In the cruise mode, control is by conventional airplane elevators, rudder, flaperons and spoilers.

Leading edge "umbrella" flaps and large deflection trailing-edge flaps reduce download and ground effect turbulence in hover. Operation of flaps, umbrellas and elevators, as well as phasing out of the rotor controls, is programmed to relieve pilot workload. A limited authority stability augmentation system (SAS) includes feedback from angle of attack, yaw angle and dynamic pressure during hover and STOL conditions. This provides increased static stability and reduces blade loads to increase fatigue margins. The aircraft can be flown with the feedback system inoperative.

4.2.2 DESIGN MODIFICATIONS TO TILT ROTOR RESEARCH AIRCRAFT

The USAF stowed rotor research aircraft design concept is based on the Boeing Vertol M222 Tilt Rotor Research Aircraft. To keep costs to a minimum, the maximum number of parts common to the M222 aircraft will be used.

In order to achieve this the following changes will be made to the M222.

4.2.2.1 Drive System

4.2.2.1.1 Rotor Drive and Engine

The engine nacelle in its present location on the M222 prevents blade folding so the T53-L-13B engine and nacelle must be relocated. It is proposed that they be mounted just inboard of the tilt nacelle beneath the wing at about W/S 160. The wing must be modified extensively to accommodate engine mounting; reorientation of the modified engine transmission and a new in-line bevel transmission with an overrunning clutch mechanism incorporated. The existing interim bevel transmission is moved from the outboard pivot position to the inboard position and a new 100% capacity pinion cartridge is plugged into the inboard side of the main transmission. One hundred percent (100%) capacity shafting is required from the engine to the rotor transmission. The existing 50% capacity cross shafting is

used between the in-line bevel boxes thus maintaining the one engine inoperative capability. The fuel cells affected locally by the engine relocation would have to be modified for clearance. Rerouting of lube lines and engine controls would be necessary as would redesign of the engine mounting and engine nacelle fairings.

4.2.2.1.2 Rotor Hub and Nacelle

A new folding rotor hub is required along with an extensive developmental test program. The operation of the proposed folding rotor hub shown in Figure 3-15 is described in Section 3.3.1. A stacked bearing retention system is used because the magnitude of collective pitch required to feather the blades cannot be accommodated by the existing elastomeric design. The elastomeric bushings become excessive in length when designed to the larger collective range and cannot be housed in the available space. Redesign of the blade socket is required but the basic blade construction may be used as is. The inboard trailing edge of the cuff must be modified to provide clearance with the upper controls in the initial stage of folding. A new pitch link/actuator which must be developed and extensively tested is required to provide the feather pitch capability without an increase in the space required for upper controls. Apart from the pitch link change, the upper controls remain as

C2

designed. A rotor hub indexing mechanism is required to index the rotor blades into the correct position for folding. The nacelle rear fixed fairing must be redesigned to provide a support structure and blade securing lock mechanism for the folded blades. The forward nacelle which is the tilting portion requires an extensive fairing change to provide a flush platform for the folded blades. The tilt actuator system can be used as is.

4.2.2.1.3 Rotor Transmission

A redesign in the rotor transmission is required to accommodate the rotor fold actuator and servovalve system. Removing the input pinion from the outboard side and blanking the outboard side is also required. Redesign of the spinner is then necessary to fair the folded hub. The installation of appropriate hydraulic lines and fold position indicators completes the nacelle changes.

4.2.2.1.4 Cruise Flight Jet Thrust Engine

The engines used for the cruise configuration and during the folding of the rotors are Garrett-Airesearch TFE-731-2 Turbofans. These engine nacelles will be positioned immediately

beneath the wing at approximately W/S 110. This location was preferred to a location on the aft fuselage which creates an aircraft balancing problem and would require estensive rework to the aft fuselage.

The engine nacelles are kept close to the wing in order to retain an adequate aircraft turnover angle and to minimize the effect of the jet thrust vector on the aircraft trim. This installation requires local strengthening of the wing to take the shear loads induced by engine weight and thrust loads.

4.2.2.1.5 Empennage

The empennage requires complete redesign to the "T" tail configurat on. The original position of the horizontal stabilizers would have caused adverse affects due to the impingement of the turbofan exhaust. Redesign of new elevators and control linkages in the aft fuselage will be required.

4.2.2.1.6 Wing

In addition to the reinforcement described in Sections 4.2.2.1.1 and 4.2.2.1.4, changes will be required in both the download alleviating umbrellas and the flaperons. These changes are necessary because of the repositioning of the T53-L-13B nacelle and the addition of the TFE-731-2 nacelle. Changes to the umbrella section are necessary for opening clearance with the TFE-731-2 turbofan engine and will include lengthening the outboard section and shortening the inboard section. Stationary fairings are then required immediately above the engine. The flaperons will be modified to prevent shrouding the T53-L-13B exhaust during hover operation by lengthening the inboard flap and shortening the outboard flap. Again a stationary trailing edge fairing is required immediately above the engine.

4.2.2.1.7 Fuselage

Only minor changes to the fuselage are required. Changes to the cockpit include the addition of cruise engine controls and instruments and the controls and instruments required for the rotor fold system. Some structural reinforcement may be required in the aft fuselage to support the T-tail. Also, it may be necessary to add fuselage fuel cells to accommodate the required fuel load. New landing gear and beef up of the landing gear attach point and support structure is required to accommodate the higher gross weight.

4.2.2.2 USAF Search and Rescue Demonstrator

It is proposed that the stowed and/or tilt rotor research aircraft be modified as shown in Figure 4-3 to demonstrate the rescue capability of the stowed rotor vehicle.

The preparation of this demonstrator will include the installation of a rescue winch and cable similar to that of the CH-46 and the installation of all applicable electrical and hydraulic subsystems.

The rescue cable will pass through a system of pulleys exiting from cabin door. The cantilever door necessitates the redesign of the door aperture structure to increase the load carrying capability.

Since the litters will not be required for the rescue demonstration, sample installation only will be made which will demonstrate the method of installation.

4.2.3 WEIGHTS

The weight empty of the stowed rotor research aircraft is 11,589 pounds. It was developed using the Boeing-Vertol Model 222 tilt rotor research aircraft group weight statement (Weight Empty 9230 pounds) as a base, Reference 2. The tilt rotor weight was adjusted as necessary to reflect the modifications associated with the stowed rotor configuration as described in Section 4.2.2. Table 4-2 presents the Model 222 group weights,

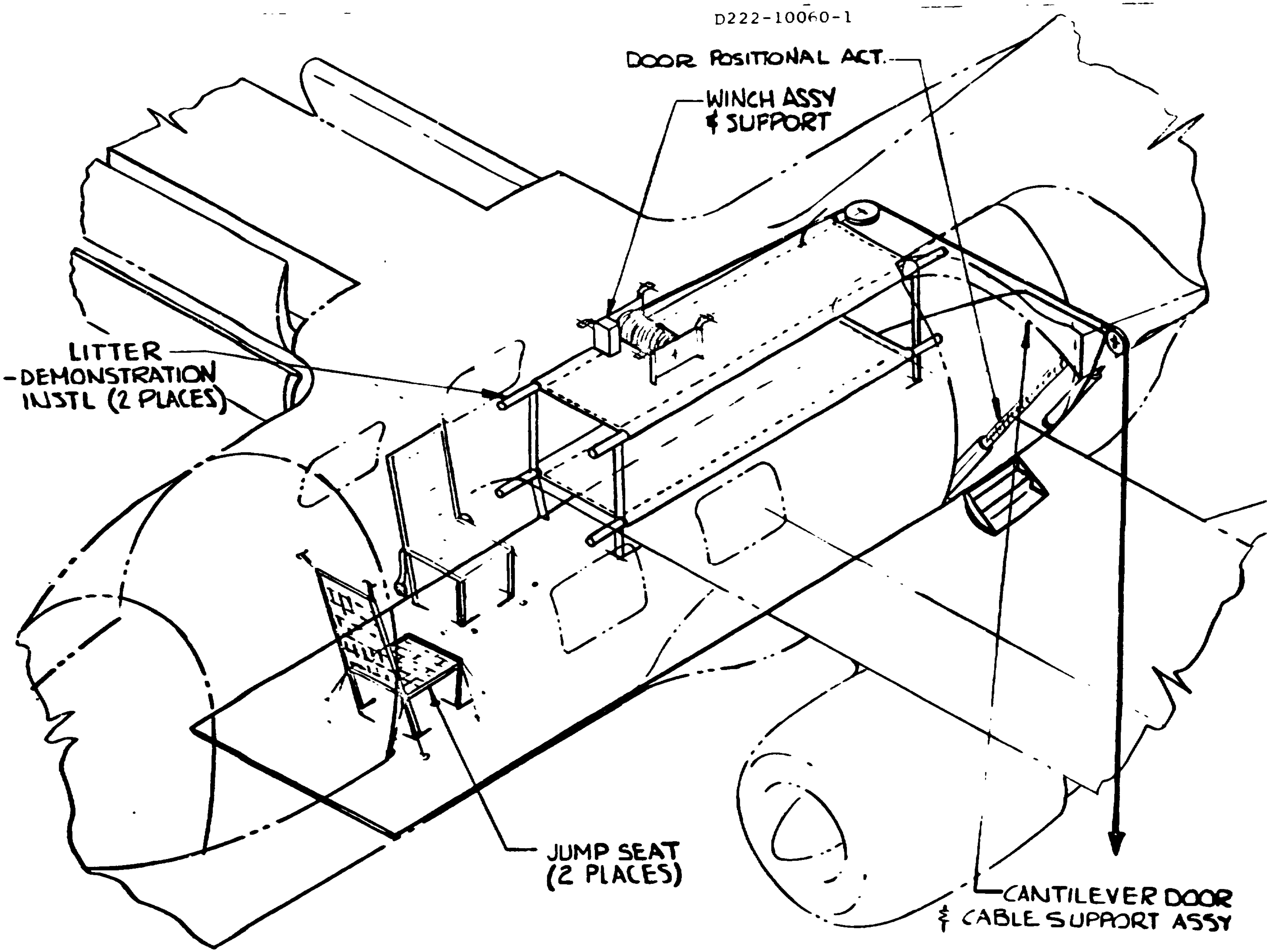


FIGURE 4-3 RESEARCH AIRCRAFT PROVISIONS FOR RESCUE DEMONSTRATION

a general description of the changes required to make a stowed rotor configuration and the resulting group weights of the stowed rotor aircraft.

The design gross and fuel weight solution for the aircraft was obtained by plotting fuel weight required and fuel available versus gross weight as shown in Figure 4-6. Fuel required is shown for the basic one-hour mission and one with a six minute reduction in duration. Fuel available lines are shown for three values of instrumentation weight. The design gross weight, corresponding to a 1000 pound instrumentation payload (consistent with the March 1972 study) and a one hour mission is 15,750 pounds. Fuel required is 2726 pounds.

The sensitivity of gross weight and fuel required to instrumentation payload and mission duration can be directly read from the curves of Figure 4-4. The following values are obtained:

INSTRUMENTATION WEIGHT	GROSS WEIGHT/FUEL WEIGHT LB	
	1-HR DUR.	.9-HR DUR.
600	15230/2606	15020/2396
800	15480/2656	15250/2426
1000	15750*/2726	15500/2476

*=Design Gross Weight

4.2.4 PERFORMANCE

The performance characteristics of the stowed rotor research aircraft are summarized in Figures 4-5, 4-6, and 4-7.

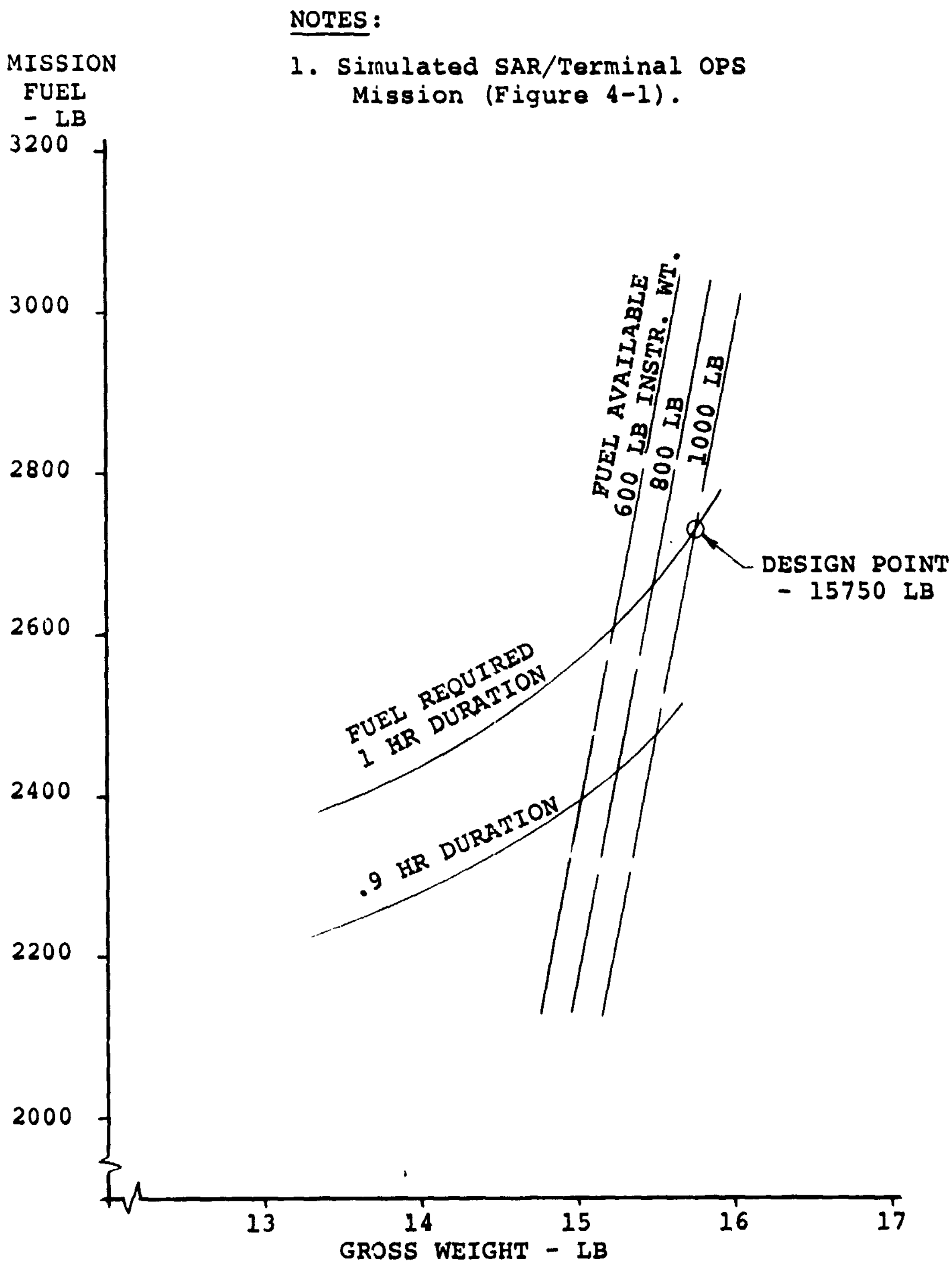


FIGURE 4-4: STOWED ROTOR RESEARCH AIRCRAFT DESIGN BROSS WEIGHT SOLUTION

TABLE 4-2 GROUP WEIGHT STATEMENT

	MODEL 222 TILT ROTOR RESEARCH AIRCRAFT	MODIFICATIONS		STOWED ROTOR RESEARCH AIRCRAFT
ROTOR GROUP	1100	Add blade folding comps.	+220	1320
WING GROUP	800	Eng.Nac.Mts.-L.E.& T.E. Chgs	+100	900
TAIL GROUP	213	Revise Horiz.Tail to "T" Conf.	+17	230
BODY GROUP	1211	Modify Empennage for Tail	+19	1230
BASIC		Changes		
SECONDARY				
SECOND.-DOORS, ETC.				
ALIGHTING GEAR	590	Strengthen gear for Incr.Wt.	+20	610
FLIGHT CONTROLS	1183	Rotor Folding &G.W. Chg.	+37	1220
ENGINE SECTION	400	Eng.Nac.Mt.& Rotor Nac.Modif.	+200	600
PROPULSION GROUP	(2533)			(4171)
ENGINES(S)	1026	Engine Change	+1420	2446
AIR INDUCTION				
EXHAUST SYSTEM	200	New Eng's & Location	+ 50	250
COOLING SYSTEM				
LUBRICATING SYSTEM				
FUEL SYSTEM	200	Incr. Fuel Capacity	+ 75	275
ENGINE CONTROLS				
STARTING SYSTEM				
PROPELLER INST.				
*DRIVE SYSTEM	1107	Drive Sys. Modif.	+ 93	1200
AUX. POWER PLANT	-			-
INSTR. AND NAV.	108	Wiring & Supports	+ 7	115
HYDR. AND PNEU.				
ELECTRICAL GROUP	305	Wiring & Supports	+ 60	365
ELECTRONICS GROUP	230			230
ARMAMENT GROUP	-			
FURN. & EQUIP. GROUP	(439)			(477)
PERSON. ACCOM.	299			299
MISC. EQUIPMENT	63			63
FURNISHINGS	35			35
EMERG. EQUIPMENT	42	Free Det & Ext due to New	+ 38	80
AIR COND. & DE-ICING	108	Eng.		108
PHOTOGRAPHIC	-			
AUXILIARY GEAR	10	Additional Hard.Points &	+ 3	13
		Struct.		
MFG. VARIATION				
WEIGHT EMPTY	9230	+	2359	11589
FIXED USEFUL LOAD				
CREW		NOTE: An additional weight		360
TRAPPED LIQUIDS		Penalty of 100 Pounds is		75
ENGINE OIL		charged to the auxiliary		
		gear group when rescue		
FUEL		winch installation is		2726
~~XXXX~~ Instrumentation		added - see Figure 4-2		1000
PASSENGER./TROOPS				
GROSS WEIGHT				15750

* INCLUDES ____ LB. XMNS. OIL

REV.

Out-of-ground-effect hover capability at L/W=1.0 is shown in Figure 4-5 for standard and 95°F day conditions. The download/thrust ratio has been increased by one percent of thrust over the tilt rotor research aircraft (See References 1 and 2) to 6%. The additional 1% is estimated to account for the addition of the cruise engine nacelles and the resulting reduction in download device area (flaps and umbrellas).

Maximum OGE hover gross weight for sea level, standard day conditions is 15,300 pounds. Since this is less than the design gross weight of 15,750 pounds, it will be necessary to make a STOL takeoff for the full one hour research mission of Figure 4-1 with the 1000 pound instrumentation package. Ground roll will be approximately 140 feet and distance over a 50 foot obstacle will be 300 feet. VTOL takeoff can be made if the fuel load is reduced to 2426 pounds and the gross weight is reduced to 15,300 pounds. Mission duration under these conditions shown in Figure 4-1 are held constant (35 minutes and 5 minutes respectively) and only the cruise time is reduced (from 17 minutes to 6 minutes). However, a one hour mission can be flown with VTOL takeoff at 15,300 pounds gross weight by reducing the total hover time from 35 minutes to 19 minutes and increasing the cruise time from 6 minutes to 33 minutes. In all cases, time to climb is approximately 3 minutes.

Level flight performance is summarized in Figure 4-6. Presented are speed and Mach number envelope and specific range

data for 15750 lb gross weight and standard day conditions. The aircraft is in the rotors-folded configuration with fan engines operating.

The speeds shown cover the range from stall to normal power speed. The aircraft is actually design limited to 350 KEAS or M=.567; the higher normal power speed is shown to indicate the ultimate speed capability of the aircraft.

The drag divergence Mach number for the aircraft is also shown for reference. The values shown are consistent with the 63-series airfoil used in the Model 222 tilt rotor wing. As noted in Section 3.2.1.2, however, M_{DD} could be raised somewhat by using an advanced airfoil.

Best climb performance at 15750 lb GW is shown in Figure 4-7 for standard day conditions. The results indicate very substantial climb capability with an absolute ceiling in excess of 35,000 ft.

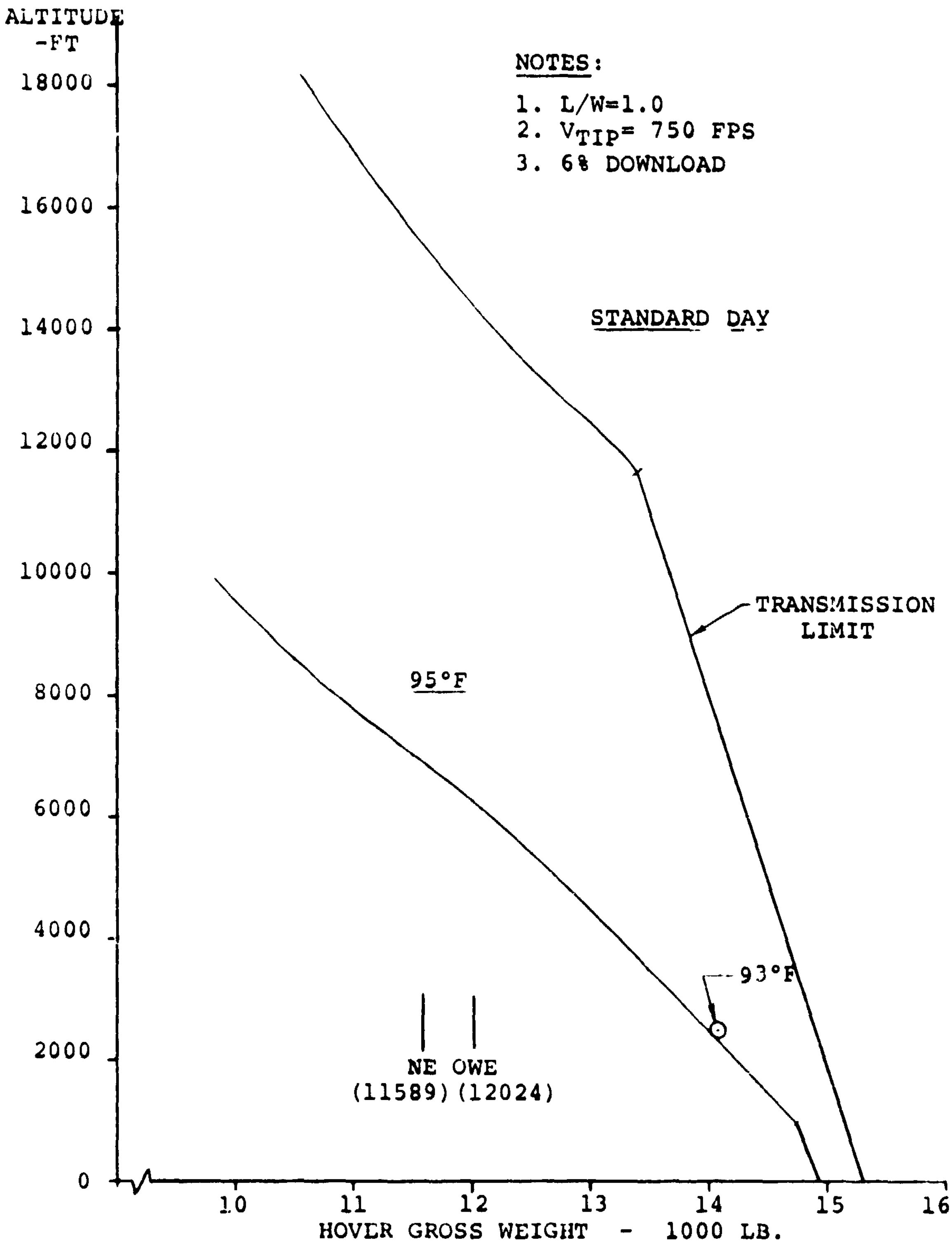


FIGURE 4-5: STOWED ROTOR RESEARCH AIRCRAFT OUT-OF-GROUND-EFFECT HOVER CAPABILITY

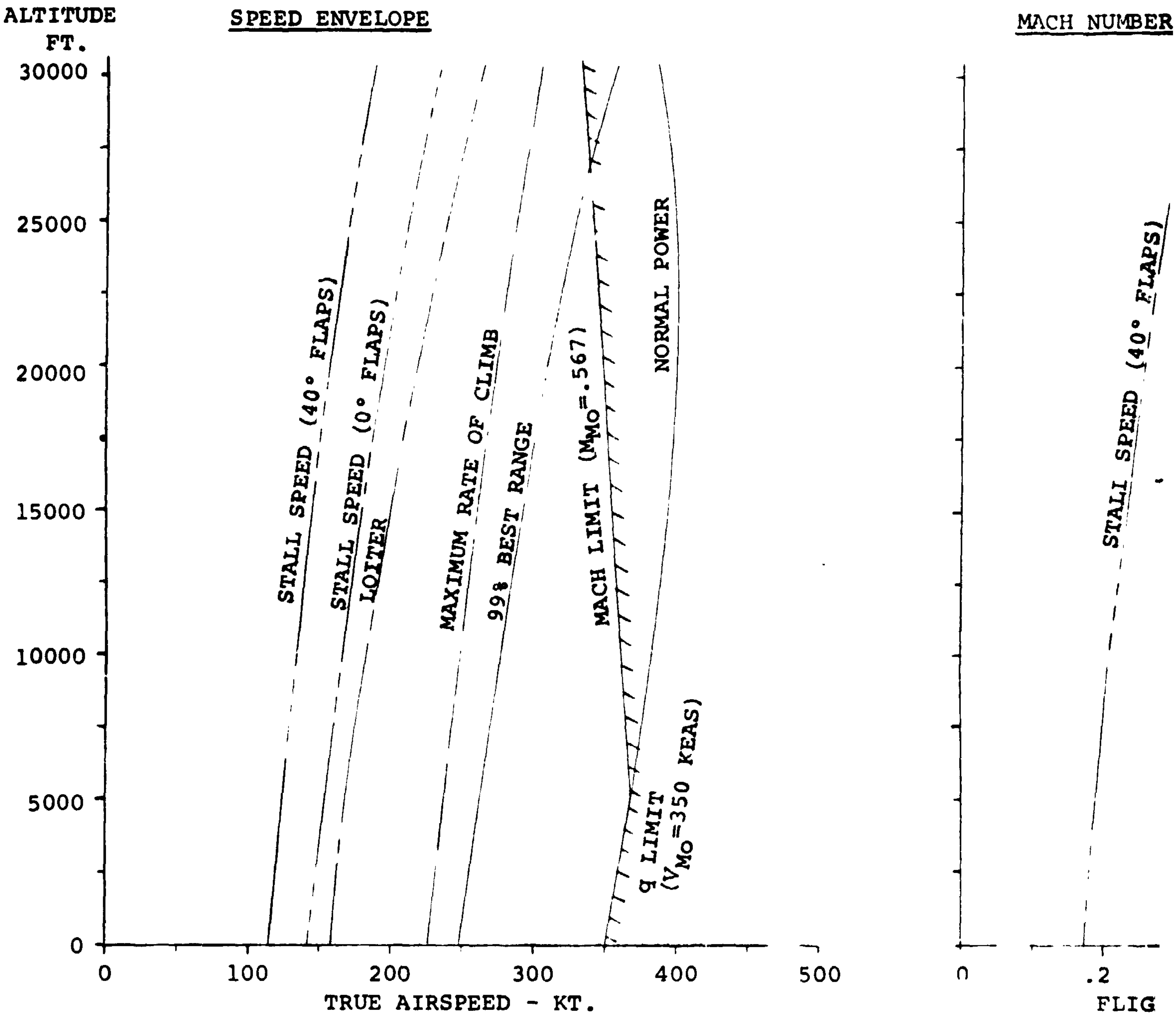
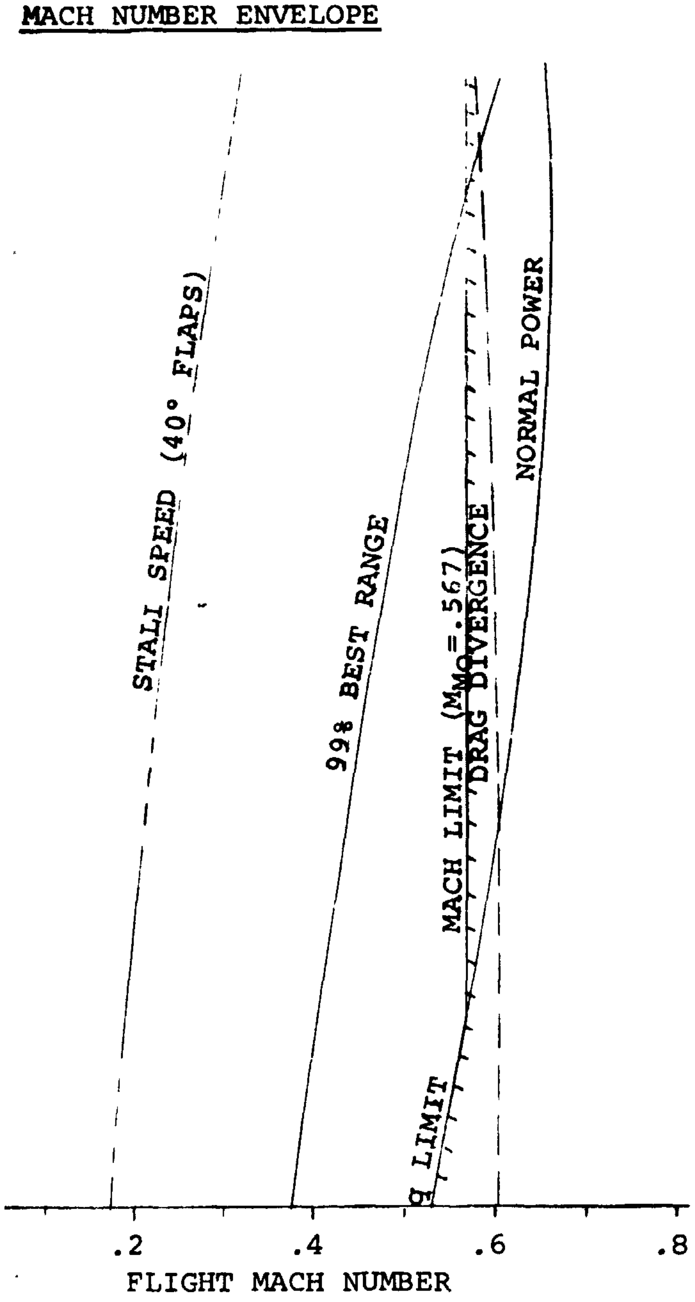
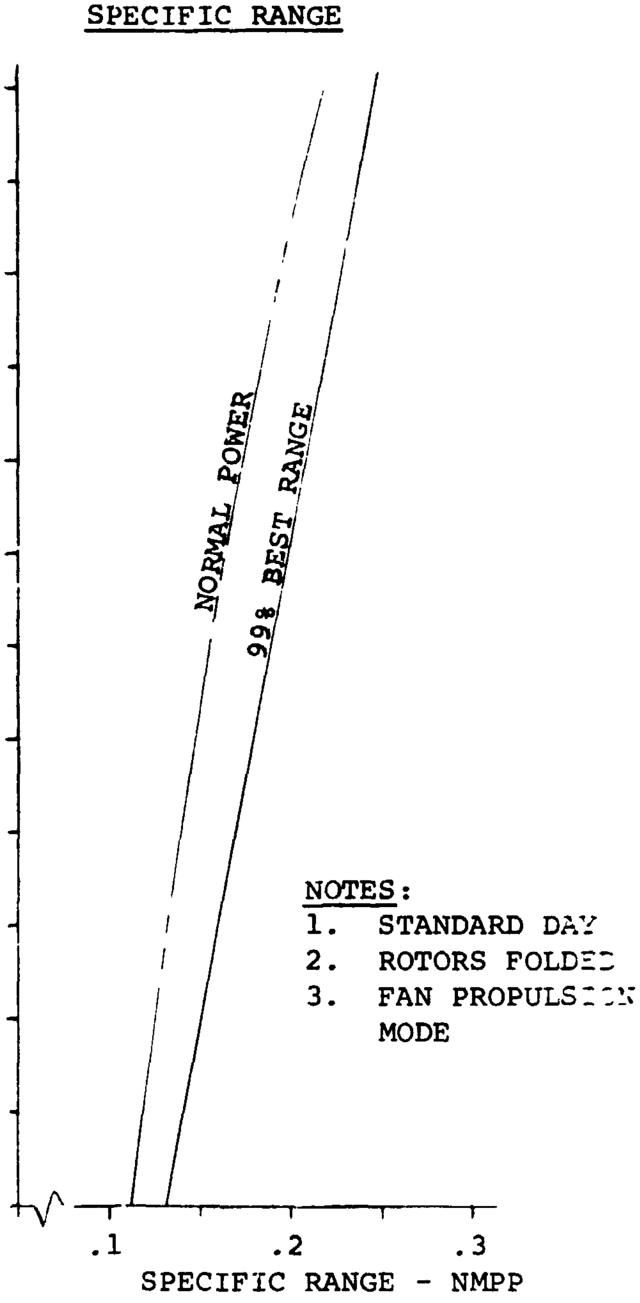


FIGURE 4-6. STOWED ROTOR RESEARCH AI
PERFORMANCE SUMMARY - 15

FOLDOUT FRAME





RESEARCH AIRCRAFT LEVEL FLIGHT
SUMMARY - 15,750 LB. GW

FOLDOUT FRAME 2

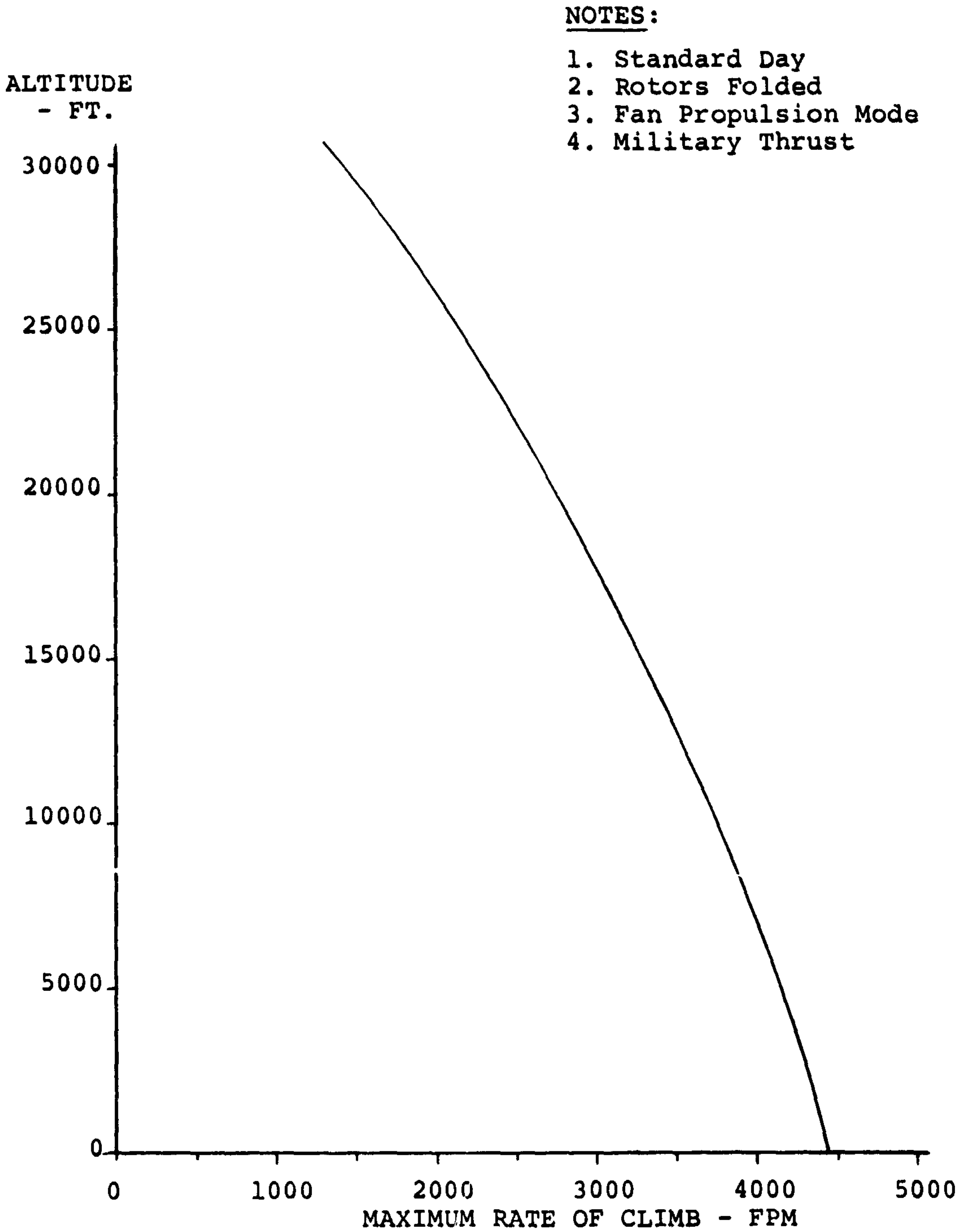


FIGURE 4-7: STOWED ROTOR RESEARCH AIRCRAFT CLIMB PERFORMANCE - 15750 LB. GW.

5.0 PROGRAM COSTS AND SCHEDULES

Section 5.0 of this volume, comprising pages 91 to 110 has been removed since it contained information considered proprietary to the Boeing Vertol Company.

6.0 WIND TUNNEL TEST PLAN FOR A FULL SCALE STOWED ROTOR RESEARCH AIRCRAFT

6.1 OBJECTIVES

1. Define the aerodynamic characteristics of the aircraft in the cruise configuration (rotors folded).

2. Verify the dynamic characteristics of the rotor/wing combination for steady windmilling conditions.

3. Confirm the power-on stability, control, and performance from hover, through transition, to maximum tunnel speed.

4. Define the collective pitch schedule to minimize transient longitudinal force and blade loads during rotor spin-up and stopping.

5. Demonstrate cruise engine start-up.

6. Define overall longitudinal force transients during thrust transfer from rotors to cruise engines, spin-down, and folding to optimize the conversion process and define pilot work-load. Also define these characteristics during conversion from cruise engine mode to rotor mode.

6.2 MOUNTING

The model support structure at the Ames 40'x80' wind tunnel is a three-point support system. A recommended installation of the stowed rotor aircraft is shown in Figure 6-1. This system is based on minimizing strut/strut/airframe aerodynamic interference and eliminating mechanical interference during the folding tests. It is a different mounting system from that proposed for the tilt rotor aircraft test, because the struts from that mount attach outboard on the wing and would interfere with the cruise engine nacelle and with the rotor blades during folding. For the stowed rotor, the forward support struts are attached to the main landing gear attachment structure. Modifications have been made to the forward support struts to incorporate both lateral and longitudinal crank, positioning the vertical members approximately 5 feet spanwise from the fuselage centerline and maintaining the aircraft center of gravity at the virtual center of the tunnel balance.

An analysis of the dynamic response of the aircraft on this mounting system will be performed. This will establish the mount stiffness required to prevent the coalescence of the airframe and rotor natural frequencies.

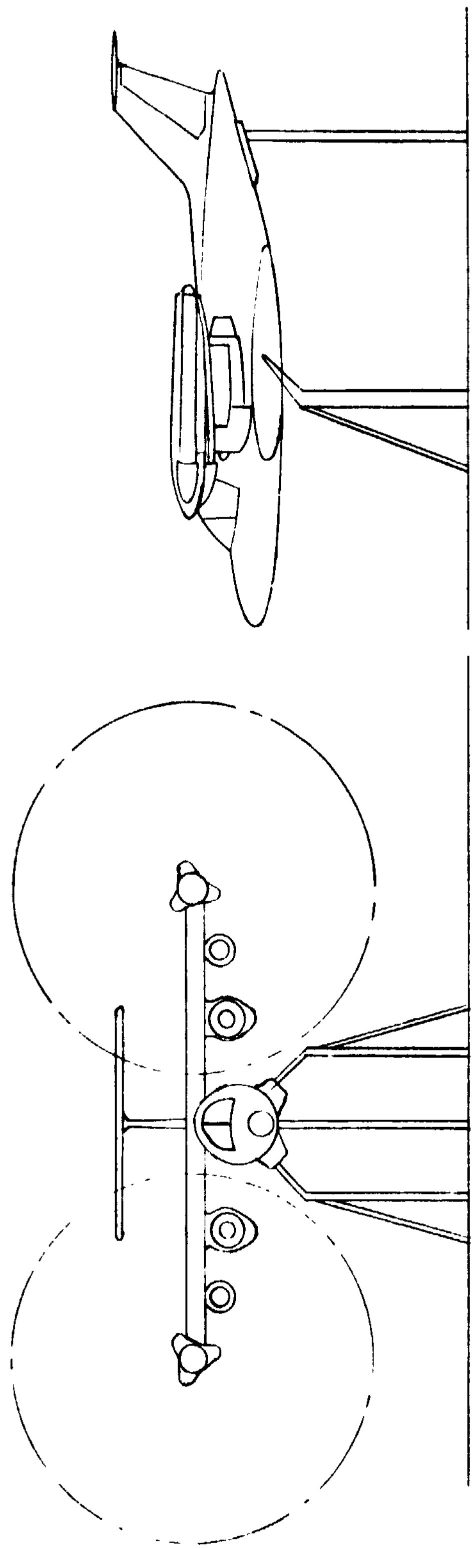


FIGURE 6-1: STOWED ROTOR AIRCRAFT WIND TUNNEL INSTALLATION

6.3 INSTRUMENTATION AND DATA REQUIREMENTS

A list of the instrumentation and data required is shown in Table 6-1. Since the model is a fully-instrumented research aircraft, the majority of the required instrumentation is integral to the aircraft. Modifications will be made to the on-board instrumentation system to permit remote display of the key parameters. In addition, a remote control and display panel will be utilized for external monitoring and control of the following aircraft functions:

a. Flight controls, both airplane and rotor
b. Engine controls for both turbofan and turboprop engines
c. Controls for rotor folding
d. Remote display of selected data

Conventional data recording and reduction will be carried out on-site at the wind tunnel. Key data will be reduced and recorded on-line in standard format.

6.4 TEST APPROACH

The model will be tested with the rotors in the folded configuration to verify predicted levels of stability and control and total airplane drag. Tests will be conducted with rotors windmilling (unpowered) at the high speed end of transition and up to 200 kts to confirm the predicted aero-elastic stability levels. Powered-rotor testing will then be conducted

TABLE 6-1

STOWED ROTOR INSTRUMENTATION AND DATA REQUIREMENTS

TYPE OF DATA	INSTRUMENTATION AND DATA REQUIREMENTS
1. Operating Conditions	Outside Air Temperature Airspeed Altitude Time Once Per Revolution Indicator Rotor Speed Rotor Collective Nacelle Incidence Pitch Angle/Yaw Angle
2. Performance (Turbo Prop & Turbo Fan Engines)	Fuel Flow Fuel Temperature Compressor Speed (N_1) Turbine Inlet Temperature Engine Torque
3. Control Positions	Longitudinal Stick Lateral Stick Directional Pedals Inboard Flaps Outboard Flaps Spoiler Swashplate Position and Angle Blade Fold Angle Indicator Elevator Rudder Actuator Positions including Nacelle Tilt Actuator
4. Aircraft Attitude and Accelerations	Pitch Attitude Yaw Attitude Vertical Accelerations - Nacelle Longitudinal Accelerations - Nacelle Angular Accelerations - Nacelle
5. Rotor Non-Rotating Control Systems Loads (Both Rotors)	Main Actuators - Tension
6. Rotor Rotating Control Systems Loads (Both Rotors)	Pitch Link 1 Pitch Link 2 Tension Pitch Link 3

TABLE 6-1 (continued)

STOWED ROTOR INSTRUMENTATION AND DATA REQUIREMENTS

TYPE OF DATA	INSTRUMENTATION AND DATA REQUIREMENTS
7. Rotor Shaft Loads	Bending Shear Rotor Torque Cross Shaft Torque Cross Shaft Bending
8. Blade Loads (Both Rotors)	Flap Bending Chord Bending Torsion
9. Aircraft Loads	Nacelle Pitching Moment Nacelle Yawing Moment Wing Vertical Bending Wing Chord Bending Wing Torsion
10. Aircraft Control Loads	Inbaord Flap Outboard Flap Spoiler
11. Total Aircraft Force & Moment Data	Lift Drag Sideforce Pitching Moment Rolling Moment Yawing Moment

to define the aircraft stability, control, and performance throughout transition.

The next series of tests will cover the spin-up from feathered condition and the spin-down from windmilling state to rotor feather. The objective will be to refine the collective pitch schedules required to minimize transient longitudinal forces during the conversion and to establish the effects on aircraft stability.

Cruise engine start-ups will be demonstrated and engine performance will be monitored.

A series of tests will then be performed to simulate a full conversion from rotor mode to cruise engine mode. The sequence and timing of the events will be studied to optimize the conversion process and to define the pilot workload. A typical sequence of events and the resulting longitudinal force history is shown in Figure 6-2. The conversion from cruise engine mode to rotor mode will also be studied.

The test is estimated to require three weeks, double shift plus three weeks installation and checkout.

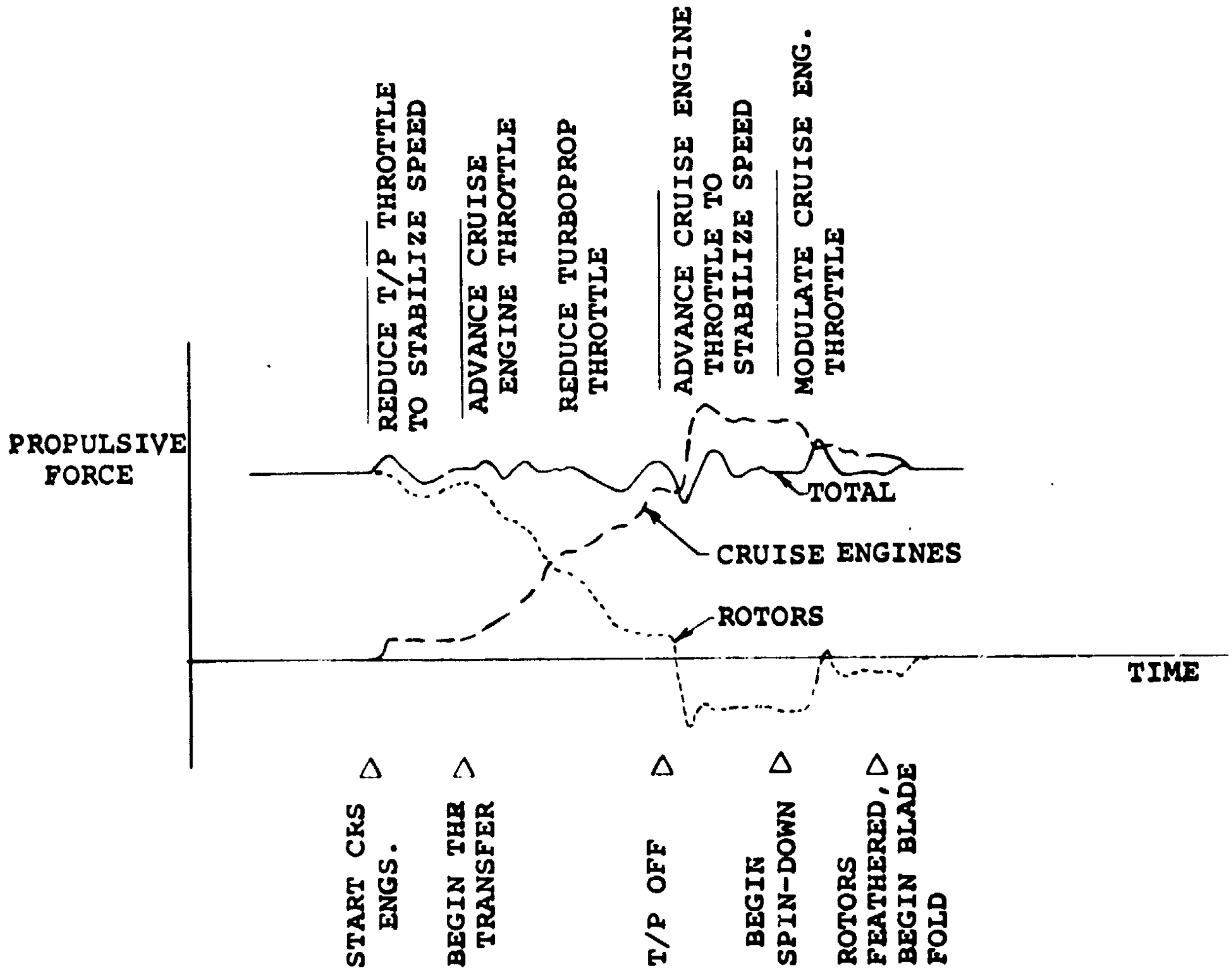


FIGURE 6-2: TYPICAL CONVERSION SEQUENCE

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